THE USE OF MULTI-CRITERIA EVALUATION AND NETWORK ANALYSIS

IN THE AREA DEVELOPMENT PLANNING PROCESS

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Abstract

The purpose of this research was to develop improvements to the area development planning process. These plans are used to improve operations within an installation sub-section by proposing alterations to the physical layout of facilities with objectives such as consolidation of personnel or facilities. One methodology was developed based on network analysis concepts as a decision support tool. It identifies locations for new facility with respect to how much they benefit from the existing functional network within an ADP study area. A second methodology was developed using multi-criteria evaluation. This methodology scores each alternative facility layout with respect to weighted objectives identified by decision makers.

The results of this study are two methodological processes that can be executed at base level requiring minimal additional information. The functional network map, based in network analysis, incorporates functional relationship data in order to create a more comprehensive generation of alterative facility layouts. The alternative layout scoring process, base in multi-criteria evaluation, returns a quantitative score for each alternative layout and a relative ranking. The use of these methodologies as decision support tools reduces the subjectivity of the current process and increases the repeatability of results.

I would like to thank all of those people who, on purpose or not, kept me working towards learning and not just finishing.

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Peeter E. Pleake-Tamm

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THE USE OF MULTI-CRITERIA EVALUATION AND NETWORK ANALYSIS IN THE AREA DEVELOPMENT PLANNING PROCESS

I. Introduction

Background

Deliberate planning of an installation's development dramatically influences how effective a given base is in supporting its missions (U.S. Army Corps of Engineers, 2012; Blevins, 1997). Effective development and management of the billions of dollars of infrastructure and facilities owned by the Department of Defense (DoD) requires thoughtful and thorough master planning (U.S. Army Corps of Engineers, 2012). A key part of this planning process is the use of the Area Development Plan (ADP). These plans govern the physical layout of installation subsections aligning them with mission supporting functions (Noritake Associates & EDAW Associates, 1991). The decisions resulting from the ADP process represent not only large capital investments, but also have long lasting impacts on the built, natural and socio-economic environments on an installation. The following effort investigates the use of network analysis (NA) and multi-criteria evaluation (MCE) to enhance the existing ADP process.

ADPs are a requirement by regulation. DoD Instruction 4165.70, Real Property Management, mandates the use of installation master plans and Unified Facilities Criteria 2-100-01, Installation Master Planning, elaborates that master planning must include the use of ADPs (U.S. Army Corps of Engineers, 2012). The installation is divided into multiple sub-areas with a unique ADP developed for each sub-area (U.S. Army Corps of

Engineers, 2012). Within the Air Force the requirements for installation master planning are identified in AFI 32-7062 *Air Force Comprehensive Planning*. This document identifies the requirements for master planning from Headquarters Air Force all the way down to Installation Commanders, while the proposed update identifies requirements all the way down to the Base Community Planner within the Civil Engineer Squadron (AF/A7CIB, 2012; Blevins, 1997). Changes to mission, requirement or command priority require an update of the affected ADPs (U.S. Army Corps of Engineers, 2012). As the ADP is intended to govern the development of an installation sub-area, changes such as the construction of new facilities or relocation of large sections of infrastructure require updates to these plans (U.S. Army Corps of Engineers, 2012). Events like Base Realignment and Closure (BRAC) mission realignments or new mission beddown are often managed through ADP updates.

Moody AFB ADP

Other events can result in the requirement for an ADP. Specific to this research Moody Air Force Base (AFB) identified a requirement to upgrade the facilities for three on base organizations. The area to be impacted by this change spanned numerous facilities and organizations creating the requirement to update the ADP. This ADP effort was initiated via contract through the installations Operations Group. The contract was let to Adkins and the contractor submitted a 90% plan in July of 2012 (Adkins, 2012). The goal of the contracted effort was to provide layout alternatives for upgraded facilities supporting the relocation of the 74th and 75th squadron operations functions and a group headquarters function for the 23d Operations Group.

This research effort began when the Base Civil Engineer's staff contacted the Air Force Institute of Technology Graduate Engineering Management program for assistance in improving this ongoing contracted ADP. One requirement of this request for assistance was to incorporate the impacts of planned actions on organizations outside of the operations group. Additionally, increasing the justification for the ADP layout selection process was desired. Both of these requirements are addressed through the proposed methodologies below. An additional component of the original request for assistance was to create an automated ADP process. However, literature review for this research uncovered work by Malakooti and Tsurushima that characterize that the ADP process, as part of the larger facility layout problem, as an ill-structured problem (Malakooti & Tsurushima, 1989). This means that the problem is not suited to a mathematical model and requires human intuition inputs as well as subjective judgments (Malakooti & Tsurushima, 1989). Beyond the facility relocations other goals and objectives of the on-going contracted ADP effort were to increase the consolidation of personnel and facilities, improve the pedestrian and vehicular traffic flow, relocate operations group agencies closer to the flightline, all while maximizing this area's ability to support future mission changes.

Research Objective

The objective of this research is to utilize NA and MCE methods to develop improvements to the current ADP process. Specifically these improvements are embodied in two methodologies based on the situation at Moody AFB. The overall question this research attempts to address is "How can the ADP process be modified to

increase its objectiveness while still being executable at the local installation level?" This is important to installations like Moody where plans may need to be generated or updated without the time or funds needed for a contracted effort.

Investigative Questions

Within the overall research objective the following two investigative questions are addressed:

1. How can functional relationship data, readily available to planners, be transformed into a product to improve the ADP layout generation process?
2. What approach can be utilized to prioritize alternative facility layouts?

The research presents two opportunities to improve the ADP process. The first investigative question addresses the under utilization of functional relationship data and how incorporating this data creates a more comprehensive awareness of factors affecting operations within an ADP study area. Data of this type is available through interviews that occur as part of the current ADP process and through archived information maintained by base and command level agencies. This research utilizes NA to analyze the relationship data and transform it into a single attribute of each facility in the ADP study area. Then Arc Geographic Information Systems (GIS), a mapping platform, is used to display the results in a functional network map that serves as a counterpart to the constraints map. The second area for improvement in the ADP process is the preferred layout selection, represented by investigative Question 2. For this question the research calculated a quantifiable score for each layout using an MCE approach. This creates a relative hierarchy and provides an enhanced justification for the selection of the preferred

layout to leadership and other stakeholders. The two methodologies developed in this research demonstrate one possible solution to each of the investigative questions posed.

Scope and Approach

This effort is focused on improvements to the Air Force process of deliberate and compatible installation development. As such, much of the justification provided and sequence of activities described are tailored specifically to the Air Force in general and to Moody AFB in particular. Focusing on ADPs, this research is not intended for application to other components of the deliberate planning process. Finally, this effort is intended to provide actionable steps for local level community planners to execute. There is no discussion provided on changes to policy.

This research begins with a review of the current BCP and ADP process. Details are provided on the overall approach and then two specific areas are identified for improvement. The next section discusses the applicability of NA and MCE methodologies to the processes of alternative layout generation and alternative layout selection. The data availability and gathering effort is then detailed. Next, a methodology is described using concepts from NA and a separate methodology is described using concepts from MCE. The NA step produces a functional relationship map, then the MCE process compares alternative layouts. Finally, conclusions and research limitations are explained.

Limitations

This effort includes limitations derived from the concepts chosen within NA and MCE as well as limitations due to the overall approach of the research. A key limitation

in the NA approach is that the process used to calculate centrality of a facility node is only valid for non-dispersed networks (Degenne & Forse, 1999). A second key limitation in the NA approach is the use of survey responses in both the degree centrality and power calculations. The use of survey inputs incorporates a large degree of bias. While this bias can be mitigated by increasing the number of personnel interviewed this value will still be affected by the limits of each individual's vision.

The MCE methodology chosen incorporates subjectively assigned criterion weights from the customer; this is purposefully done in order to reflect the differences in priority between criteria (Voodg, 1983). Furthermore, the choice of assigning a single quantitative data type, referred to as a proxy variable, to represent each criterion introduces a high dependency between criteria and proxy variable. Furthermore, there are three requirements tied to the use of the weighted summation approach within MCE. First, criterion weight values must be gathered on a quantitative measurement scale (Voodg, 1983). Second, the raw data values must be gathered on a ratio scale and relevant to each other (Voodg, 1983). Third, data aggregation must take place through addition (Voodg, 1983). A more detailed description of limitation specific to NA and MCE can be found at the end of Chapter 3.

The overall research approach incorporates additional limitations. The scope of the ADP effort evaluated was the relocation of only three agencies. Attempts to apply this approach to efforts where the scope of mission change is much greater could render this approach overly burdensome. The use of this research is limited to organizations that possess in-house public works departments with knowledge and resources similar to Air

Force Civil Engineer (CE) squadrons. Finally, this effort is limited to generate decision support tools, not to replace planners or decision makers.

Preview

The remainder of this thesis is divided into four chapters. Chapter 2 includes a literature review covering the terms and concepts that are the basis for this research effort. It also highlights the current ADP process and identifies where in the existing process improvements can be made. Chapter 3 includes justification for the selection of the NA and MCE methodologies. Furthermore, details are provided on the data requirements, data gathering process, and data manipulation needed to apply NA and MCE methodologies in order to improve the ADP process. Chapter 4 presents the results of the two methodologies with regards to the NA functional network map and the MCE alternative layout scores. Chapter 5 reviews key findings and limitations for this research, and discusses the significance of the research effort and future research opportunities.

II. Literature Review

Chapter Overview

The following literature review is divided into four topic areas. The first section describes the current area development plan (ADP) process. The second portion provides background on network analysis (NA) and justification for its selection in this research effort. Background and justification for multi-criteria evaluation (MCE) is then provided. The final section describes ArcGIS and the tools used within that program for this effort.

Generation of Area Development Plans

AF installation planning guidance is contained in Air Force Instruction 32-7062, titled *Air Force Comprehensive Planning*. At the installation level, this instruction takes the form of a base comprehensive plan (BCP). The ADP is one of several subcomponents that make up the Capital Improvements Program (CIP) Plan (Blevins, 1997). The CIP itself makes up one portion of the Component Plans, which are in turn one of the four main sections of the BCP (Blevins, 1997). This relationship is illustrated in figure one below.

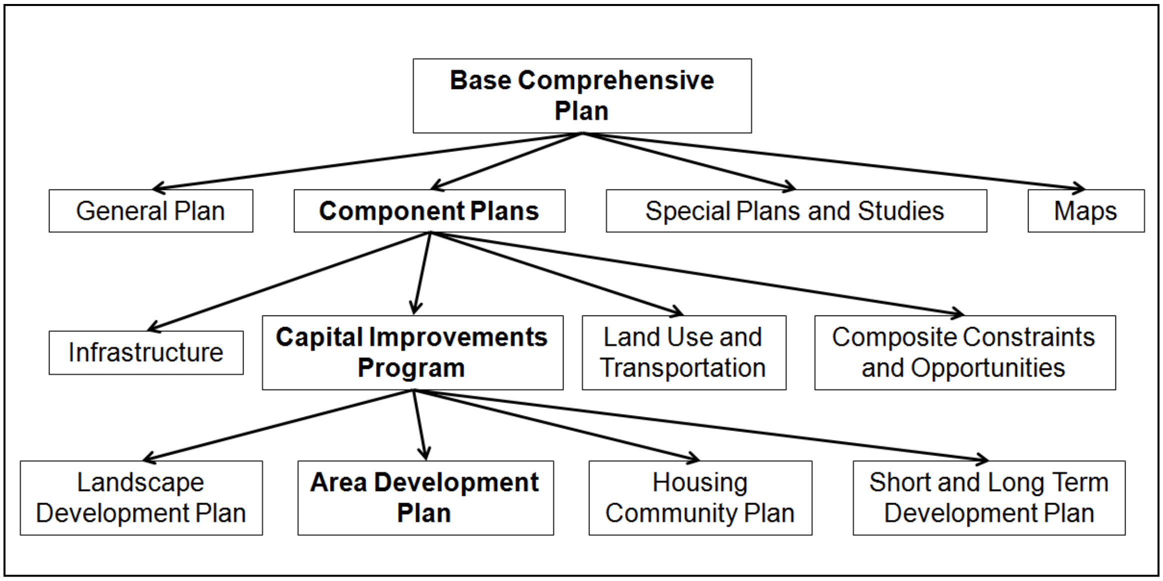


Figure 1. Comprehensive Plan Components

The ADP itself examines a specific area within an installation. This subsection of the installation is bounded by either a similar function or architectural characteristic (Noritake Associates & EDAW Associates, 1991). For the purposes of this effort, the subsection's boundaries on the installation are defined by function only. ADP's fulfill a requirement for detail and analysis that falls between what is provided by the General Plan, which covers the entire installation, and a site plan, which lists specifics for a single facility only (Noritake Associates & EDAW Associates, 1991). The ADP is able to reflect the added complexities incurred when evaluating effects across multiple facilities, while still being able to provide actionable recommendations for enhancing a single portion of the installation, instead of the overall guidance found in base general plans. Typically, AF installations are divided into six general functional groups; these are airfield operations, industrial, administrative, housing, community, and outdoor recreation (Noritake Associates & EDAW Associates, 1991). In order to generate the

optimal plan for the area in question, the ADP utilizes several urban design principles. These include land use compatibility, spatial and functional relationships, area development, vehicle and pedestrian circulation, landscape architecture, and architectural compatibility (Blevins, 1997). The result of the NA portion of this effort builds on spatial and functional relationship principles. The ADP generates alternative development strategies by utilizing these standards over a limited portion of an installation with respect to improving operations for that area's primary function.

While ADPs are described in Air Force Instruction 32-7062, the primary purpose of that document is to provide guidance on comprehensive base development. The stated goal is to establish "a systematic framework for decision-making with regard to the development of Air Force installations" (Blevins, 1997). A revised version of the document, still in draft form, emphasizes integrating the systematic installation physical development with investment planning processes (AF/A7CIB, 2012). This planning process incorporates inputs from other Air Force programs to include operational, environmental, and urban planning. In addition, this process is bounded by all applicable laws, regulations, and policies from within the DoD, Federal, State and Local governing bodies (Blevins, 1997). The AFI explains that the planning process should include most of the installation's agencies. Moreover, impacts on and inputs from affected off base individuals or organizations should be incorporated (Blevins, 1997). The end product of this process takes the form of the installation BCP. According to the AFI, the BCP should be a document that "encompasses those specific resource documents and processes … essential for planning and managing an installation's physical assets in support of the mission" (Blevins, 1997, p. 9). Furthermore, plans should tailor the

information presented to the appropriate level. The level of detail present in an ADP would be too burdensome if incorporated into a base general plan. The BCP itself is made up of four planning documents: the general plan, the component plans, special plans and studies, and reference maps (Blevins, 1997). The general plan is a broadly based document intended for installation commanders and other high level leaders to aid their decision making process with regards to overall base development. It is a picture of the capabilities and delivery systems that support the mission, as well as a general overview of infrastructure with respect to assessing possible development opportunities (Blevins, 1997). Component plans are more detailed documents consisting of graphical and textual data (Blevins, 1997). These plans typically focus on a single function supporting an aspect of the general plan. Special plans and studies also provide detailed information on a specific function; however, in this case each plan or study is required by a specific regulation or policy (Blevins, 1997). Reference maps make up the last component of the BCP and are included to support or provide additional detail to any of the plans mentioned above (Blevins, 1997).

Component plans, while not required by regulation, are typically generated to enhance the installation's planning efforts with regards to a specific concern, and are divided into four groups. The first group is the composite constraints and opportunities plans. This plan summarizes natural and cultural resource information as well as airspace and operational safety restrictions. By combining these data, the plan highlights areas on the installation that have limited development opportunities or are subject to unique development constraints. Heavy emphasis is placed on compliance with environmental and safety regulations. The second planning document making up the component plans is

the infrastructure plan. This document contains an overview of the utility systems with regards to condition, capacity, and other characteristics. Emphasis is placed on analyzing the benefits and costs of possible infrastructure investments. Effort is also given to highlighting the connections between utility systems and how they affect development opportunities. The third group of these plans is the land use and transportation plan. As the title suggests there are two components to this plan. One of these, the land use plan, maps the various functions of all activities on the installation. It also identifies planning factors and details the process used to determine future land use. Relationships among activities are also included therein, with the more important relationships justifying a closer spatial proximity between the agencies making up the relationship. The final product of this analysis is the future land use plan which provides general information to decision makers on installation growth and development similar to a zoning map. The second component analyzes not only on-base, but off-base influences on the transportation network. The goal of this plan is to improve the efficiency of the network and guide future road development. The last of the component plans is the CIP. This plan focuses on traditional physical planning and includes elements such as current land use, both on the base and in the surrounding area, existing installation layout and facilities, and the existing transportation network. These plans are combined with their corresponding future plans into a single document making up the CIP. Also, all funded and programmed future construction projects are identified and included in the CIP. This includes construction projects categorized as those funded through military construction, operations and maintenance, military family housing, non-appropriated funds, moral welfare and recreation, depot maintenance industrially funded, and others. The goal of

the CIP is to identify and capture all known projects possessing a scope large enough to significantly alter the physical layout of the installation. Other facility development programs are also described, such as architectural compatibility and landscape development. The final components of the CIP are those generated to investigate alternative development strategies, which include ADPs (Blevins, 1997).

Beyond this general guidance on the overall comprehensive planning process, an ADP bulletin was developed through a collaborative effort of Noritake Associates and EDAW Associates. This document defines an ADP as a plan which "examines a specific area within an installation which is unified by its function or architectural character" (Noritake Associates & EDAW Associates, 1991, pp. 1-1). Another goal of the ADP is to improve the functional operations of a specific area within an installation. This document also highlights the important connection between the Long Range Facilities Development Plan (LRFDP) and the ADP. The LRFDP is five year outlook for all future military construction projects. Integration of inputs from this document is critical as military construction projects are typically large enough in scale to effect a change in both land use and numerous functional relationships. The ADP is also described as the critical link between the overall development guidance, provided by the general plan, and the facility specific guidance provided by the individual site plan. Since the ADP addresses a smaller section of the overall installation, more detail can be included and focus can be given to enhancing the primary function of a particular section of the base. Furthermore, by being broader in scope than a site plan, the ADP allows elements like vehicular and pedestrian circulation, as well as the disposition of areas between facilities, to be addressed. This bulletin also lists several common reasons for pursuing the ADP

process. One of these, the need to focus on an area due to a number of pending construction projects, is one of the reasons the effort at Moody AFB began (Noritake Associates & EDAW Associates, 1991).

The ADP process itself is also described in this bulletin. Figure 2 below from the *Area Development Planning Bulletin* illustrates an overview of this process which is then explained in more detail (Noritake Associates & EDAW Associates, 1991).

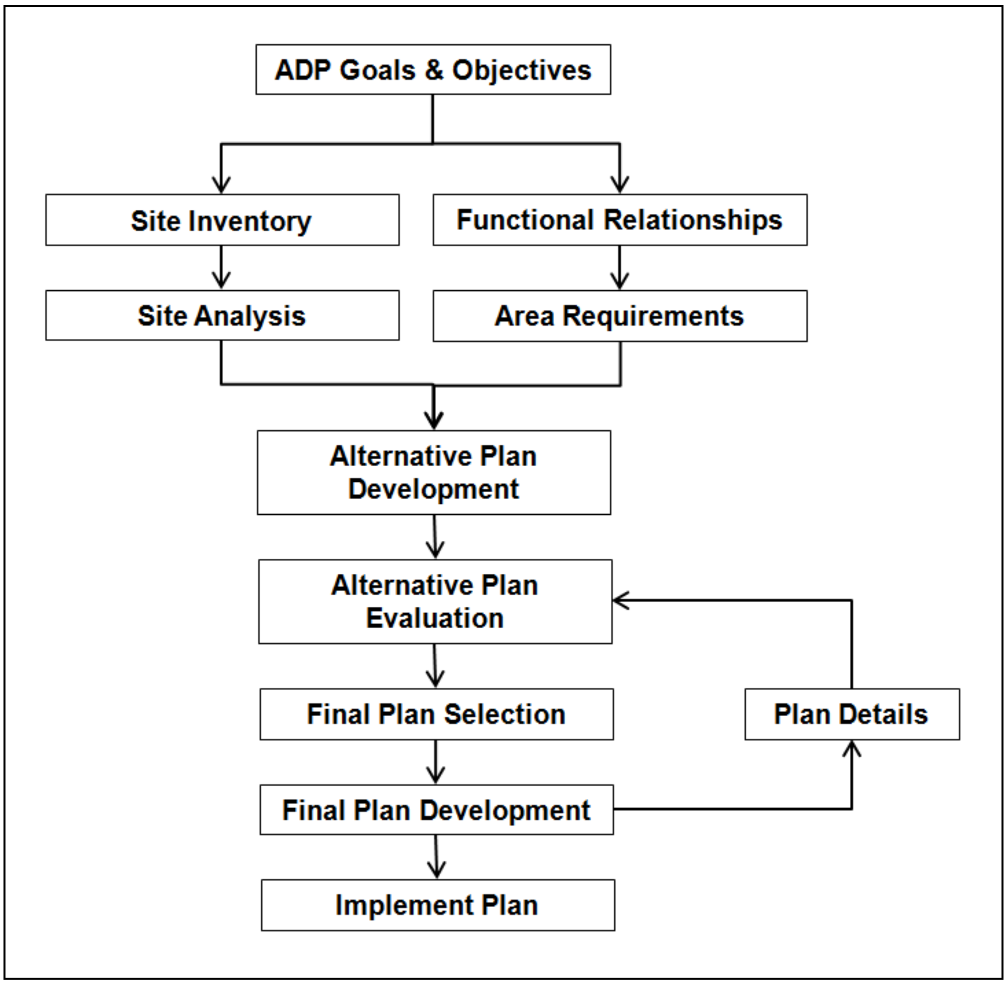


Figure 2. ADP Process Chart (Noritake Associates & EDAW Associates, 1991).

The ADP process begins after the development of the base's general plan, which identifies all of the smaller functional areas. First, goals and objectives are defined by

both the users in the area and appropriate leadership agencies across the installation. Following this, upcoming projects in the study area are identified. This includes a list of new or modified facilities and infrastructure in the affected area, identification of funding sources, scope of the proposed projects, and the project timelines. As mentioned above, some of these inputs are also drawn from the LRFDP and other similar sources. After the upcoming projects have been identified, other types of data are collected. The planning bulletin divides this data into three broad categories: those that are associated with the natural environment, those associated with the built environment, and those associated the socio-cultural environment (Noritake Associates & EDAW Associates, 1991). Natural environment data include items such as flood plains, topography, or vegetated areas. The built environment data includes facilities, roads, or utility information. Socio-cultural environment data consists of the functional relationships between agencies, the amount of capacity available for support of mission fulfillment, or the identification of historical buildings. Data collection is significantly guided by the goals and objectives defined earlier in the process (Noritake Associates & EDAW Associates, 1991).

The ADP planning bulletin identifies the next step as site analysis. This is accomplished by generating three maps. The first of these maps encompasses all the natural environmental elements in the ADP area. The second map represents all the elements of the built environment. The third map is generated by using the first two maps to create a single opportunities and constraints map. Where the first two maps note the applicable attributes of built or natural elements, the third map assigns values to these attributes and determines if an attribute is either a benefit or drawback to the primary function of the ADP area. A key output of this map is the identification of developable

land. Once the developable land has been identified, the land area requirements for the new projects are gathered. This includes not only the physical footprints of these projects, but the associated space requirements as well, such as building setbacks, parking lots, required open spaces and access points (Noritake Associates & EDAW Associates, 1991).

According to the planning bulletin, the final requirement is gathering the functional relationship data. This involves identification and evaluation of the functional relationships between the agencies within the ADP area. These relationships are typically identified through a series of site visits and interviews with both the current and projected agencies that will populate the affected area. There are very few details provided for the integration of this data into the remainder of the ADP process, which is discussed further later in this chapter (Noritake Associates & EDAW Associates, 1991).

After all the data collection is complete, the constraints and opportunities map is finished, the new facilities area requirements are identified and the functional relationship data has been gathered, the alternative development layouts are generated. While there is no minimum or maximum number of layouts required for evaluation, typically three or four are developed through a non-linear process involving multiple iterations. Alternatives are generated by combining the expert opinion of planners with the data and analysis described above. Each layout includes a list of benefits and drawbacks based off of the objectives outlined in the ADP. Some examples of these objectives are functional compatibility, vehicular and pedestrian access, utility capacity, and architectural considerations. Alternatives are then judged by selected decision makers who review the layouts and evaluate each using additional considerations such as a comparison to an

ideal solution, future expansion needs, and costs (Noritake Associates & EDAW Associates, 1991). After inputs are gathered from the decision makers, a final plan is selected either by a governing authority or consensus. The subjective nature of the selection decision is an area of concern in this process discussed later in this chapter. Additionally, the decision making process can highlight additional details or factors that are fed back into the evaluation of alternative plans. The final step in the ADP process is plan implementation, which typically involves generating a project list for inclusion into the LRFDP or other execution program. Overall the ADP process seeks to create a more functionally effective layout by mapping all physical attributes of the area, gathering inputs from the agencies within the area, developing alternative plans, selecting a final plan based on inputs from decision makers, and then implementing the plan though an execution program (Noritake Associates & EDAW Associates, 1991).

Significance of Functional Relationship Data

This research effort uses NA to produce a visual representation of the functional network data gathered in the ADP process. Ideally this map will be used in conjunction with the opportunities and constraints map described above to facilitate the generation of alternative layouts. The significance of incorporating this functional relationship data is highlighted in the sample master statement of work developed by the Air Force Center Engineering and the Environment (AFCEE), now part of the Air Force Civil Engineering Center, in 2005. While this document is primarily intended for prospective contractors and contracting personnel to describe the entirety of this effort, it provides a detailed list of 27 tasks required to complete an ADP (AFCEE, 2005). Of those tasks, three address

aspects of the functional relationships between facilities. Task 11 addresses the requirement for the contractor to identify the “cornerstone facilities” in the affected area (AFCEE, 2005). Task 14 requires an analysis of the functional relationships between the agencies in the ADP area. Finally, task 18 requires the contractor to identify facilities and functions that would benefit from relocation (AFCEE, 2005). The generation and use of a functional relationship map is one approach to fulfilling these three requirements.

Network Analysis

One of two primary groups of data gathered during the ADP process is information on the functional relationships between agencies that reside within the geographic boundaries of an ADP study. While the constraints map is built off of data from the built and natural environments, functional relationship data is built from the socio-economic environment. The current process gathers this type of data through interviews with personnel affected by the ADP (Noritake Associates & EDAW Associates, 1991). However, archival data such as organization charts or real property records can also supply this type of information (Degenne & Forse, 1999). While the current guidance notes that relationship data should be an input into the generation of alternative layouts, unfortunately it only provides rudimentary methods to analyze and display this information (Blevins, 1997; U.S. Army Corps of Engineers, 2012). Two of these approaches provided in the *Area Development Planning Bulletin* are the functional compatibility matrix and the functional relationship diagram shown below in Table 1 and Figure 3 (Noritake Associates & EDAW Associates, 1991).

Table 1. Functional Relationship Table (Noritake & EDAW, 1991)

(solid black)	Collocation Desired
(hatched)	Compatible
(white)	Incompatible

	Exchange	Commissary	Personnel Support Functions	Library	Chapel	Clubs	Gym/Recreational Facilities	Child Care	Open Space
Exchange									
Commissary	Collocation Desired								
Personnel Support Functions	Collocation Desired	Collocation Desired							
Library	Compatible	Compatible	Compatible						
Chapel	Compatible	Compatible	Compatible	Compatible					
Clubs	Compatible	Compatible	Collocation Desired	Incompatible	Incompatible				
Gym/Recreational Facilities	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible			
Child Care	Incompatible	Incompatible	Compatible	Compatible	Compatible	Incompatible	Compatible		
Open Space	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Collocation Desired	Collocation Desired	

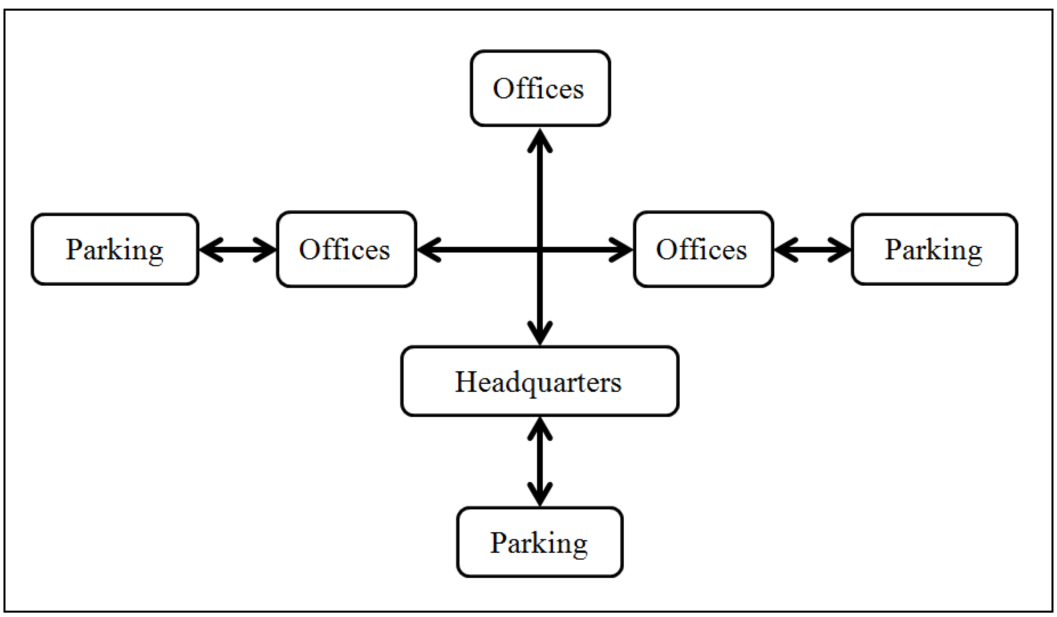


Figure 3. Functional Diagram (Noritake & EDAW, 1991)

The functional relationship table provides guidelines for co-locating or not co-locating functions based on a general function category. The functional diagram provides an

analysis of a specific organization and the agencies that make it up. Each box indicates an agency within the organization and the arrows represent interactions between agencies. The goal of this diagram is to co-locate those agencies which interact with each other. These approaches have two significant shortcomings. First, neither the matrix nor the diagram produces a final result that can be directly displayed or overlaid on a facility map of the ADP area. The generation of alterative layouts for further analysis within the ADP process is often heavily influenced by identifying those areas on the facilities map that appear available for development when constraints data is overlaid. The lack of an overlay representing the functional relationship data minimizes its influence on possible layout identification. Second, while both of these approaches highlight the linkages or connections between the buildings in an ADP planning area, neither approach can illustrate physical layout alternatives.

By utilizing NA this research proposes a way to transform functional relationship data into a single attribute that can be displayed on a facilities map to represent the interaction level each building had with the functional network in the ADP area. NA, specifically social network analysis (SNA), provides methods to refine this type of data and produce a final product that can effectively illustrate the effects of these functional relationships. At its most basic SNA is a way to study social structures, made up of individuals or groups, by analyzing the ties that link its members (Wellman, 1983). In this way each individual or group within the network is represented by a node and the interactions between individuals or groups become the ties or links that connect nodes to one another.

Once this network is mapped, further analysis can be performed by studying the patterns these ties make and inferring how these associations affect the access of a node or group of nodes to other variables (Wellman, 1983). These additional variables can vary from access to resources or information to more abstract concepts like power or influence. The goal of the ADP process is the development of an optimal layout of facilities to support the efforts of the individuals and groups working in them. For this effort the facilities within the study area of an ADP become the nodes of the network and the interactions between the individuals and groups operating out of each facility are the links between the facility nodes.

Utilizing relationship data, the facility nodes are then evaluated with two NA methods. The first of these is degree centrality, which evaluates the number of links to a single facility node in the network in order to evaluate the centrality of that node (Degenne & Forse, 1999). For this evaluation, the greater the number of links to a particular node within the network the higher the evaluated node's centrality is (Degenne & Forse, 1999). The process of counting each node's number of connections limits degree centrality to determinations of local centrality only (Degenne & Forse, 1999). For non-local centrality measurements, such as centrality determinations for a dispersed network, other methods should be applied (Degenne & Forse, 1999). In a dispersed network scenario certain nodes provide the only path linking otherwise isolated groups of nodes (Degenne & Forse, 1999). The position of these nodes within the network provides them higher level of centrality than would be apparent by just counting their connections. This research assumes that due to the various groups and numerous personnel operating out of each facility node, the functional network is not dispersed in

nature and therefore degree centrality is an appropriate evaluation process. The second analysis method, facility node power, measures the influence each node exerts on the network and can be evaluated by how an additional factor or resource travels through the network (Degenne & Forse, 1999). For example in this research the volume of e-mails generated and received at each facility node was selected as an indicator of that facility nodes power. The higher the e-mail volume the more influence that facility node has on communication within the network. E-mail traffic then becomes a measureable signal variable representing communication influence as an aspect of power. The results of these two methods are then combined to indicate the level of interaction within the functional network each building node has.

The interaction score is a concept developed in this research effort to represent both the degree centrality and power of each facility node within the functional network. The combination of degree centrality and power into a single concept creates an attribute that can be visual represented on a map. This representation takes the form of a green to red gradient covering the entire ADP study area. This gradient can be used to predict areas for development that will improve the efficiency of operations with respect to the functional network. The ability of the gradient to improve efficiency is based in two elements. The first of these elements is the fact that each facility has a different level of impact on operations within the network. This is based on the varying interaction score calculated by summing the degree centrality and power values. The second element is the connection between spatial distribution and efficiency.

This research assumes that the closer facilities are distributed together, the more efficiently they will operate. This assumption is based on a relationship between distance

and decision speed which has been investigated in information richness theory, also referred to as media richness theory. Fundamentally, this theory addresses “the ability of information to change understanding within a time interval” (Daft & Lengel, 1986, p. 560). While the connection between information richness and decision quality remains a subject of debate, research shows a relationship between information richness and decision speed (Dennis & Kinney, 1998; Suh, 1999). In these studies face to face communication resulted in faster decision making times than text based communication, such as e-mail (Dennis & Kinney, 1998; Suh, 1999). Thus the research assumes that decreasing the distance between facilities will increase the number of face to face communication exchanges, which in turn increases the speed decisions are made improving the efficiency of operations within the ADP area.

By combining the varying level of impact on operations per facility with increased efficiency due to decreased facility separation, the gradient identifies new facility sites with respect to functional relationship data optimized by spatial distribution. As the gradient is built on subjective values for degree centrality and power, color categories were chosen as the visual display. Based on intuitive association, green was selected to represent desired areas and red as the un-desired areas. The end product is a map where the green gradation areas represent locations where it is desirable to site new facilities and red areas are locations that are not desirable.

Once the functional network map is completed, planners can use this map in conjunction with the constraints map to focus planning efforts onto specific locations within the ADP study area. Locating new facilities in green coded areas results in compact development and encourages infilling of undeveloped space, both of which are

principles in the draft comprehensive planning AFI (AF/A7CIB, 2012). The use of the gradient is what ultimately completes the visualization of raw relationship data into a map that can be used to enhance the physical layout of an ADP study area by refining the identification of alternative layouts through incorporating functional network data.

Multi-Criteria Evaluation

Another area for improvement in the current ADP process is the selection methodology used to choose the preferred facility layout. The MCE approach has been applied successfully to both the facility layout problem and assessing trade-offs in transportation planning scenarios (Shang, 1993; Zia, Koliba, & De Pinto, 2012). MCE has also been combined with GIS and applied to site selection and spatial searches in multiple efforts (Carver, 2007; Jankowski, 1995). The current ADP layout selection process is to choose a single layout by obtaining a consensus from the decision making body (Noritake Associates & EDAW Associates, 1991). While no single layout meets every goal or objective of the plan, indeed goals within an ADP often partially or completely conflict, the decision making body chooses a single layout as the preferred option from those generated for selection. This subjective approach lacks tangible evaluation criteria. Furthermore, the installation master planning Unified Facilities Criteria stipulates that ADP evaluation should be based on measureable criteria (U.S. Army Corps of Engineers, 2012). The use of defined evaluation criteria is key when addressing future decision makers concerns.

The MCE concepts used in this research belong to a larger family of models referred to as multi-dimensional decision and evaluation models (Carver, 2007). The

fundamental purpose of these models is to address balancing multiple and possibly conflicting goals (Carver, 2007). A key aspect of these evaluations is that they are based upon multiple criterions resulting in a more complete analysis between alternatives (Voodg, 1983). The same is not true of other methods which may generate comparisons utilizing a single criterion, such as cost benefit analysis. Within this family of models the MCE approach focuses on evaluations of future plans or actions; this aligns the model to the investigative question stated above (Voodg, 1983). Moreover, MCE should only be utilized when there are discrete set alternatives to evaluate such as the typically three to four layouts generated in the ADP process (Voodg, 1983).

A final distinguishing characteristic of MCE is in the area of explicit decision. The MCE decision making process is an explicit approach focused on transparency and accountability of results whereas the current ADP process can be said to belong to an implicit approach, where bargaining between decision makers results in a solution (Voodg, 1983). In the case of this research the generation of explicit results is desirable to provide unbiased justification for the selection decision made. Specifically MCE's basic aim is "to investigate a number of choice possibilities in the light of multiple criteria and conflicting priorities" (Voodg, 1983, p. 21).

The MCE approach, also referred to as multi-criteria analysis, evolved from an identified shortfall in neoclassical economics in the 1970s (Carver, 2007). This development was driven by a need to adequately weigh the negative impacts of ill defined consequences such as pollution costs or health risks (Carver, 2007). Previous approaches attempted to compare various goals by assigning each an artificial price in order to create a common scale, whereas the MCE approach retains appropriate units of

measure for each of the various criteria (Carver, 2007). Another development is the recognition that all input criteria do not have equal importance to decision makers. To accommodate this variance the MCE approach includes the application of weighting factors, selected by the user, to each evaluation criteria (Carver, 2007). The inclusion of both the original units of measure for each criteria and the use of weighting factors alters how the raw data is analyzed. Once all of the raw scores for each criterion have been gathered, an evaluation matrix is constructed. This matrix is the heart of the MCE approach; one axis lists the alternatives available and the other axis lists the evaluation criterion (Voodg, 1983). The raw scores are then standardized; this additional step is required because a common scale, like dollars, is not present. The resulting matrix, like the example shown below, is then ready for analysis.

Table 2. Notional Evaluation Matrix

	Criterion 1	Criterion 1 Normalized	Criterion 2	Criterion 2 Normalized
Alternative A	10	0.5	1	0.333333333
Alternative B	15	0.75	1.5	0.5
Alternative C	12	0.6	3	1
Alternative D	20	1	2.2	0.733333333

For this research the weighted summation technique was selected as the analysis method for the evaluation matrix. This is the most common method for urban planning and also incorporates the weighting factors mentioned above (Voodg, 1983). There are three basic assumptions that must be fulfilled to correctly utilize this approach. The first requirement is that criterion weight values are gathered on a quantitative measurement scale (Voodg, 1983). The second is that the original measurement scores are determined in a ratio scale so that they are relevant with respect to each other (Voodg, 1983). The

final requirement is that the aggregation of information takes place through summation (Voodg, 1983). As discussed in Chapter 3 this research effort meets all three of these requirements. The weighted summation approach simply multiplies each normalized criterion score by its weight and then totals a score for each alternative. The alternative with the highest score is selected as the preferred alternative. The end result of this process is a ranking of possible solutions with regards to the most attractive resultant outcome influenced by all of the input criteria.

ArcGIS and Tools

ArcGIS was selected as the platform to perform the spatial analysis steps in this research effort. Fundamentally this program supports the collection, organization, management, analysis and communication of geographic information (What is ArcGIS?, 2013). There were three primary reasons to utilize this platform. First, the Moody facility map was available only in this program. Second, the use of ArcGIS has become the standard for Air Force CE squadrons to manage their base maps in as it meets the GeoBase program requirements outlined in AFI 32-10112, Installation Geospatial Information and Services (AF/A7CIS, 2007). Using this platform to perform the spatial operations enables base level CE personnel to easily duplicate these steps for other ADP efforts. Third, this program includes the four analysis tools described below that meet the spatial analysis needs for this research effort. The first of these tools calculates the minimum distance between two objects, called the Near command in ArcGIS (Near (Analysis), 2013). The second tool generates a series of standoff distances from a facility, called Multiple Ring Buffer in ArcGIS (Multiple Ring Buffer (Analysis), 2013).

The third tool applies a mathematical operation to a column of values similar to what is possible in Microsoft Excel, called the Field Calculator (Making Field Calculation, 2013). The final tool takes overlapping influences that are applied across a geographic area and sums them together to determine the total influence on a specific area, called SuperRegionPoly v93 (Snyder C. , 2009). As discussed above, the use of the ArcGIS platform not only enhances this research's applicability to base level users, but the program includes tools that facilitate a much faster and less error prone analysis.

Summary

This chapter reviewed the guidance behind the development of ADPs as well as summarized the current development process. As discussed above, the current process of alternative layout generation underutilizes functional relationship data. NA presents one opportunity to capture the centrality and power aspects of functional relationships for inclusion into alternative layout generation. The current process for alternative layout selection lacks a measureable ranking of the various layouts. MCE can be used to incorporate multiple objectives and requirements into a single score for each alternative. The next section will develop and discuss a methodology for generating a visual display of the functional relationships in a proposed ADP area in order to provide additional inputs to planners generating alternative ADP layouts. Additionally, a process for ranking proposed alternative layouts to determine a preferred solution is developed.

III. Methodology

Chapter Overview

The goal of this research effort is to develop two methodologies to improve the area development plan (ADP) process. Specifically one methodology transforms the functional relationship data gathered early in the ADP process and transforms it into a visual display used in the generation of alternative layouts. The second methodology generates a score for each alternative layout based on multiple goals and objectives identified by the customer. The following section begins with a discussion of data requirements for the network analysis (NA) and multi-criteria evaluation (MCE) methodologies. Next, the data acquisition and data manipulation required to apply NA and MCE analysis is described. Then, discussion is provided on the sensitivity analysis performed on the MCE weighting of proxy variables. The final section of this chapter addresses methodology specific limitations.

Data Requirements

This research effort required data types that were unique to each methodology as well as data types that were used in both models. Both methodologies required the use of the spatial distribution of facilities within the ADP study area. Specific to the NA methodology, at least one data type had to be identified to represent the centrality of each facility node, and another data type was required to represent the power of each facility node. Furthermore, the facilities comprising the functional network had to be provided. The MCE first required the identification of the goals and objectives of the ADP by the customer. After these had been selected, a data type had to be chosen to represent each

goal or objective. The final required input was the specific alternative layouts identified in the contracted ADP drafts. While the assignment of a single data type to each requirement is the minimum, this research assigned more than one data type to certain requirements, when they were available, in order to reduce the dependency between requirement and data type.

Data Acquisition

The data for this research was gathered from Moody AFB in Georgia. The information requested was provided either by the contractor, Adkins', or by the CE and Communication squadrons. In certain situations where the desired information was not available, it was assumed as discussed below. The base facilities map was provided by the CE squadron and was utilized in both methodologies to represent the existing and proposed facilities spatial position within the ADP study area. For both methodologies the study area is defined by the encircled region in Figure 4 below.

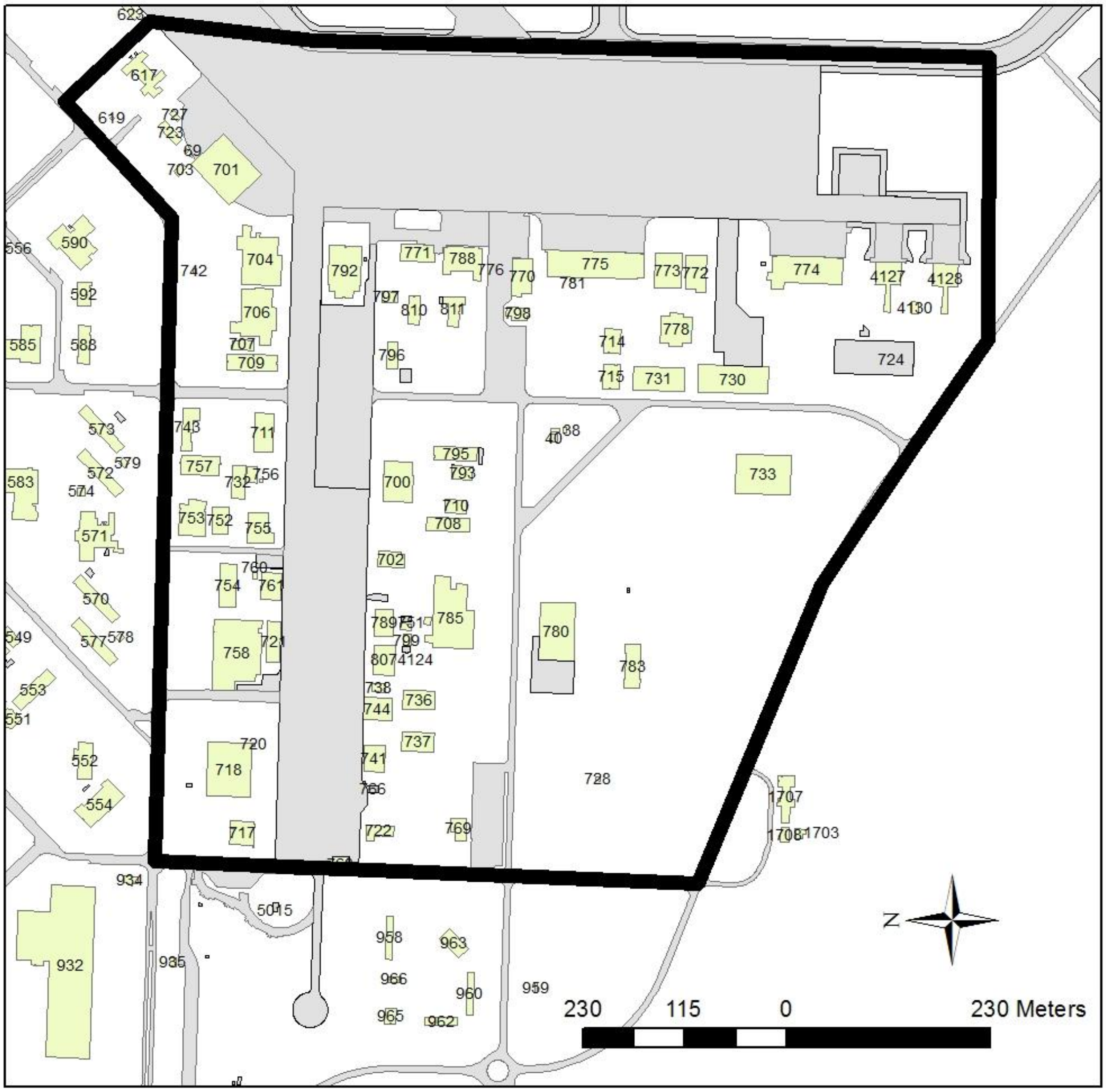


Figure 4. ADP Study Area

This area's primary mission is aircraft maintenance. Specifically, the southern portion of the airfield supports A-10 aircraft and includes thirty nine inhabited facilities.

Network Analysis Data Acquisition

In order to represent both the degree centrality and power aspects of the NA, a minimum of two data groups were needed. While only two data groups are required this research effort identified a total of four data groups that would be available to local planners to provide a more comprehensive picture of the functional network data. The objective of the NA portion of this research is to demonstrate a feasible process; where real data was not available, simulated data was used. A final key input for this methodology was the identification from the CE squadron of the facilities to be evaluated. Moody CE identified 39 buildings to be incorporated into the functional network map. The overall goal of the NA methodology is to transform these four data groups into a single attribute that can be displayed on a facilities map to incorporate functional network data into the alternative layout generation process performed by installation planners.

The first data group consists of survey responses from key personnel working in facilities located within the ADP study area. Simulated inputs were generated for the results discussed in Chapter 4. The personnel selected for this survey should come from leadership or managerial positions that possess a level of awareness of all activities occurring within the facility being evaluated. Survey recipients should be asked to list all of the facilities in the ADP study area that they or the personnel working in their facility must interact with to fulfill their day to day mission. The values assigned to the 39 facilities were generated by a random function bounded between 1 and 38. Bounds were based on informed assumptions from literature review to ensure the incorporated data did not invalidate the methodological analysis being applied (Degenne & Forse, 1999). If

planners wanted to integrate this NA methodology into a new ADP effort this data requirement could easily be met during the standard initial ADP data gathering interviews with key personnel in each facility falling within the ADP study area.

The values assigned to this data type are then used to calculate the degree centrality for the facility being evaluated. The degree centrality is the sum of each facility that the facility node being evaluated interacts with (Degenne & Forse, 1999). This value is then standardized by dividing each building's score by the maximum score so that the highest normalized value is 1. Equation 1 below illustrates the normalization approach used through this research effort as this is the preferred method of normalization for this type spatial study (Voodg, 1983).

$$V_n = \frac{V_{ij}}{V\max} \tag{1}$$

Where:

V_n = Normalized value (1 to n)

V_{ij} = Actual ith value listed from 1 to j

Vmax = Maximum value listed from 1 to j

The final normalized degree centrality value was then saved for each of the five simulated facilities to be incorporated with the power portion of the interaction score as described below.

The remaining three groups of data needed for the NA methodology are all used to calculate the power score for each facility node. For this effort the power of a facility node is defined by three components. These components are the importance of the

facility node to overall mission, the importance of the facility node to functions within the ADP study area, and the frequency of interactions between the evaluated node and the other nodes in the network. The operational definitions for these three components are described below.

The mission dependency index (MDI) was used to define the importance of the facility node to the overall mission. Specifically the MDI is an "Operational Risk Management metric used to communicate the relative importance of a facility in terms of mission criticality." (USAF, 2012) The MDI raw data was represented as a score from 0 to 100 with the higher the score signifying a greater reliance between the facility in question and mission completion. The MDI is assigned to each facility based on its category code. The value for each category of facility was determined at the Air Force corporate level, with the majority of values ranging between 30 and 90. This information was available and provided by the Moody AFB CE squadron. Raw scores were normalized prior to being incorporated into the overall power score.

The third group of data used in the NA portion of this research is a set of survey results from key personnel used to represent the importance of the facility node to functions within the ADP study area. Similar to data group one, the respondents should be in leadership and managerial positions and this data could be gathered during initial interviews in the ADP process. For this data group, interviewees would be given a certain fixed number of importance points to distribute across the facilities in the ADP study area. They would assign points to facilities based on how significant they feel each facility is to operations within the ADP area. The more important an interviewee feels a facility is the greater the number of importance points he or she assigns to that facility.

This data is simulated in the results section. For each facility a single response was generated distributing 100 importance points across the 39 facilities being evaluated. To distribute these 3900 importance points the 39 buildings were randomly divided into low (10 buildings), medium (20 buildings) and high (9 buildings) importance groupings. Low importance facilities were assigned one point per response for a total of 39 points per building. Medium importance buildings were assigned two and one half points per response for a total of 98 points per building. High importance buildings were assigned nine points per response for a total of 172 points per building. One high importance building was assigned a total of 174 points to result in a total distribution of all 3900 points possible. The points for each facility are then normalized. It should be noted that the results reported in Chapter 4 below do not represent the functional relationships present on Moody AFB due to the simulated assignment of these, and other, survey responses.

The fourth group of data for this portion of the NA is the volume of e-mail generated and received per facility per week. This data represents the frequency of interactions between the evaluated facility node and the other facility nodes in the network. While software to accomplish this type of data gathering, referred to as a network counter, is available free online, it would have to be created and installed by the Communications squadron in order to operate on Air Force networks. This research effort used assumed e-mail traffic volumes over a week. In order to simulate this data group several assumptions were made. A population was assigned to each of the modeled facilities based on an average of 264 square feet per person (ACC/A7PS, 2012). This value was multiplied by the total square feet for each building to establish a

population per building. Based on research by the Radicati Group each person was assumed to generate 37 e-mails per day and receive 65 e-mails per day (Hoang & Radicati, 2011). It should be noted if the network counter was used directly the assumptions about population and email volume are not needed. The total amount of e-mail traffic was then calculated for each simulated facility and the raw scores were then normalized using Equation 1.

Following the collection and normalization of the four data groups, a facility multiple ring buffer representing the interaction score can be generated. The degree centrality score calculated from data group one is then added to the power score which is generated by summing data groups two through four. Equation 2 and 3 below illustrates the calculation of the centrality and power score.

$$D_c = D_1 \tag{2}$$

Where:

D_c = Degree Centrality

D_1 = Normalized data group one – centrality survey

$$P = D_2 + D_3 + D_4 \tag{3}$$

Where:

P = Power

D_2 = Normalized data group two – MDI

D_3 = Normalized data group three – local importance survey

D_4 = Normalized data group four – e-mail volume

The interaction score is then calculated by adding the power and degree centrality values together as shown in Equation 4 below.

$$I = \left(D_C + P\right) \tag{4}$$

Where:

I = Interaction score

Once the interaction score was calculated for each facility, this data was transferred into ArcGIS for mapping. The details for the ArcGIS processes performed are contained in the procedure log for Generation of Functional Network Map within Appendix A. The mapping effort includes two inputs, the 39 facilities to be evaluated, as identified by Moody CES, and the installation facilities map. The first mapping step creates influence zones around each evaluated facility through the use of polygons. For this effort zones were created out to 225 meters. This ensured that at least one zone covered all parts of the ADP study area. Attributes were then assigned to each of these

polygons based on the facilities interaction score. The next step is to modify each polygons attribute to account for the distance from the influence generating facility. This is done by applying equation 5 to each polygon.

$$T_s = I * (250 - Buff\_Dist) \tag{5}$$

Where:

Ts = Total score

I = Interaction score

Buff_Dist = The specific buffer being evaluated

After this equation was applied, 351 polygons are then assigned an attribute indicating a specific level of influence with regards to a specific distance from an evaluated facility. Subtracting the Buff_Dist value from the constant 250 inverts the values so that the total score is highest for the buffers closest to the perimeter of the evaluated facility and lowest for buffers farthest away. Although polygons are generated out to 225 meters the constant 250 is chosen to account for the 0 to 25 interval. In this way the total score value reflects the assumption from literature review that minimizing distances between facilities increases efficiency of operations (Dennis & Kinney, 1998; Suh, 1999). The next step was to add up the influence exerted on all regions of the ADP study area from all the evaluated facilities. To do this the user generated script SuperRegionPoly V93 was chosen. This script first identified each case of polygon overlap and assigned them a unique identifier. Once this was complete all the polygons are separated into these unique areas. Next the script merged the polygons portions together and then summed the interaction score attribute. This resulted in a new single layer of polygons covering

the ADP study area with an attribute based on all of the influence exerted on that area due to all of the evaluated facilities. The final step was to apply color coding to the attribute field. A green to red color ramp was selected with the highest attribute scores assigned green colors and the lowest red. This map is the visual representation of the functional network. Planners can then use this map as an additional input for the generation of alternative ADP layouts.

MCE Data Acquisition

The MCE analysis for this effort required six additional data groups in addition to the spatial facility data provided by the base facilities map. All six of these data groups were available for this research to demonstrate the use of MCE as applied to an ADP effort. The overall goal of this methodology is to generate a relative score for each alternative layout to aid in the selection of the preferred alternative as well as provide additional rational for the selection of one alternative layout over another. The first data group is a set of alternative layouts to evaluate. This was provided by the contracted Adkins ADP. The plan identified four alternative layouts; see appendix B for alternative layouts A through D. Another data group was required for each objective identified by the customer. For this research the customer, Moody AFB CE, identified five objectives for the ADP shown in Table 3 below. As the objectives do not lend themselves to direct quantitative measurement, proxy variables were assigned for each objective. The proxy variables were selected based on selections made in similar research and available data (Carver, 2007; Zia, Koliba, & De Pinto, 2012). Finally, weighting factors were provided for each proxy variable based on the priority of each objective within the ADP area.

Weights were provided by the CE squadron representative based off of a distribution of 100 priority points across all of the objectives (Rozzoni, 2012). The weights' effect on the final ranking of alternatives is addressed in the sensitivity analysis section below. Table 3 below shows the objectives, proxy variables and weights for this MCE analysis effort.

Table 3. ADP Objective, Criterion and Weight

Objective	Criterion/Proxy Variable	Units	Weight
Consolidation of facilities	Demolished facility area subtracted from constructed facility area	Sqft	25
Maximize flexibility and prepare for future personnel and aircraft	Remaining land area available for development	Acres	15
Create more efficient circulation	Total distance between new facilities and all other existing facilities	Feet	30
Move fighter operations closer to flightline	Distance from new facilities to flightline	Feet	25
Consolidate fighter group personnel	Number of buildings to be constructed	Each	5

The data group for Objective 1 is made up of the total square feet of new construction and demolition for each alternative layout. This data was available from the contracted ADP plan. For each layout the total square feet of facility space to be demolished was subtracted from the total square feet to be constructed. The resulting figure represented the facility growth proposed by the layout being evaluated. After the facility growth was calculated for the four alternative layouts these values were normalized as described in Equation 1 above. Each growth factor was then multiplied by the weighting factor, 25 for this objective. This process is shown in Equation 6 below.

$$C1_i = W_1 * \left(\frac{(AC_i - AD_i)}{max(AC - AD)} \right) \qquad \textbf{(6)}$$

Where:

C1 = criterion 1

W_1 = weighting factor for criterion 1

AC = area constructed

AD = area demolished

This resulted in a weighted value where the higher score indicated layouts with the least consolidation of facilities. As the goal of the objective was to maximize consolidation each score was then multiplied by negative one prior to being aggregated into the final score for their alternative.

The data group for Objective 2 consisted of the total remaining acres of land left undeveloped in each of the four alternative layouts. The ADP area was divided into land parcels A through K in the contracted ADP effort and the area of each parcel was provided. Utilizing this data each alternative layout's facility construction footprint was analyzed and the resulting number of open parcels remaining was recorded. The undeveloped acreage was then totaled. Each alternative layouts total was then normalized in accordance with Equation 1 and then multiplied by the weighting factor, 15 for flexibility. The resulting value aligns those alternative layouts with the highest score with the objective of maximizing flexibility. Due to this, the values do not need to be multiplied by negative one and were directly aggregated into the overall alternative score.

The data group for objective 3 consists of the total distance between the proposed new facilities and the remaining facilities in the ADP area. Critical to processing this data group as well as data group four is the relationship between the alternatives, the number of new buildings each alternative proposes and which agency will inhabit which new facility. Table 4 below summarizes this information.

Table 4. Layout, Facility & Agency Relationship

Alternative Layout	Facility to be Constructed	Agencies Occupying
A	A1	23 FG, 74 FS, 75 FS
B	B1	74 FS
	B2	23 HQ
	B3	75 FS
C	C1	23 HQ
	C2	74 FS, 75 FS
D	D1	74 FS, 75 FS
	D2	23 HQ

In order to calculate these values the current ArcGIS facilities map was requested and provided by the CE squadron. The specific ArcGIS process is included in Appendix A Procedure Log under Total Distance and Near Command. For each alternative layout, two groups of additional map layers were created. The first group of layers contained a single object representing a specific new facility planned for construction in the layout being evaluated. For instance alternative layout A requires the construction of a single new facility and, as such, it contained a single new layer in this group. However, alternative B requires the construction of three new facilities which resulted in the creation of three additional layers for this group. The new facilities were inserted as objects based off of a visual overlay from the contracted ADP drawings. The second

group of layers consisted of a single counterpart for each new layer created in group one. For these layers any existing facility that conflicted with the proposed footprint of the new facility was deleted. After the layers were created, the Near command was utilized to calculate the total distance from the new facility to every existing facility in the ADP area. The command returns a new column of data containing the shortest distance from the new facility to each existing facility which was then summed. This column of data was calculated for each pair of layers. The last step before calculating a total distance for each alternative layout is to account for the effect of alternative layouts with varying numbers of new facilities. As the objective for this data group is to improve the circulation of personnel within the ADP area, the distance value has to be modified to account for the collocation of multiple agencies in a single new facility. For example alternative layout A directs the construction of a single new facility with all three agencies co-located in it; the distance value for alternative layout A is then multiplied by three to reflect the total distance for each agency. However, alternative layout B directs the construction of three new buildings with a single agency in each as the process returns a total distance per new facility no multiplication factor was needed. The resulting total distance for each alternative is then normalized and multiplied by the weighting factor, 30. Similar to objective one's data, in this case the higher the score indicates an increased total distance and a less desirable alternative, as such; all scores for this criterion are multiplied by negative one prior to being aggregated in the total score for the alternative.

The fourth data group is made up of the distances between the new facilities and the airfield for each alternative layout. The raw data for this criterion was available by

re-utilizing the layers generated in the previous data group and using additional information from the base ArcGIS map supplied by the CE squadron. Similar to data group three, the Near command was utilized to calculate these distances. The specific ArcGIS process is included in Appendix A Procedure Log under Airfield Distance and Near Command. An airfield only map layer was created and the Near command calculated the shortest distance from this layer to each of the new facilities proposed in the alternative layouts. For alternative layouts which include multiple new facilities, the distances for each facility are summed and a mean value was calculated. Similar to data group three, the averages that were calculated accounted for the number of agencies in each facility. Then the distance values are normalized and multiplied by the weighting factor, twenty five. Similar to previous data groups, a higher score for this criterion indicates a less desirable alternative layout and consequently the values are multiplied by negative one prior to aggregation.

The fifth data group consists of a count of the number of new facilities proposed in each alternative layout. This data was available from the contracted ADP as shown in Table 4 above. The total number of new facilities for each alternative was normalized and then multiplied by the weighting factor, five. Again for this data group, a higher the score implies a less desirable alternative therefore the scores were multiplied by negative one.

Once all the criterion scores were calculated they were aggregated into a single total score for each alternative layout shown in Equation 7 below.

$$TS_i = (-1*C1_i) + C2_i + (-1*C3_i) + (-1*C4_i) + (-1*C5_i) \tag{7}$$

Where:

TS = Alternative layout score

C1 = Facility consolidation

C2 = Flexibility

C3 = Circulation

C4 = Flightline proximity

C5 = Personnel consolidation

The scores are only relative to each other so their relationship with zero is irrelevant. The alternative layout with the highest score represents the preferred layout alternative based on the criterion evaluated. As was mentioned at the beginning of this section, the MCE methodology should be used as a decision support tool.

Sensitivity Analysis

A key concern when using MCE with user provided criterion weights is the results' sensitivity. In order to evaluate how changes in the priority weights assigned to each criterion affect the alternative layout ranking a sensitivity analysis was performed. This was accomplished by evaluating a +/- 25% deviation in the weight for each of the five criterion evaluated, divided into broken 5% increments. As discussed above, a limited distribution of priority points, arbitrarily capped at 100, become the weighting factor for each criterion variable. In order to preserve this limit while still varying the

evaluated weights, a weight reduction factor was applied to all non-evaluated criterion. This factor was calculated as shown in equation 8 below.

$$W_r = \frac{(W_e - W_b)}{4} \tag{8}$$

Where:

W_r = Weight reduction factor

W_e = Criterion weight evaluated

W_b = Baseline criterion weight

Finally, after the adjusted total scores were determined for all alternative layouts a spider plot was generated for each criterion to display the effect of variation in weight to the resulting total score of each layout.

Methodology Limitations

The two methodologies discussed above contain several specific limitations to their applicability. The following will address these limitations in the NA and then the MCE methodologies. A key limitation in the NA approach is that the calculation for degree centrality is applicable only to non-dispersed networks. For networks with nodes that serve as links between otherwise isolated clusters of nodes, degree centrality does not return an accurate measure of the centrality (Degenne & Forse, 1999). For these types of cluster networks approaches such as betweenness centrality or closeness centrality are appropriate (Degenne & Forse, 1999). A second key limitation in the NA approach is the use of survey responses in both the degree centrality and power calculations. The use of survey inputs to identify the centrality of a given facility to the overall network as well as

identification of facilities within the ADP study area that are the most significant to the function of that area, incorporates a large degree of bias. While this bias can be mitigated by increasing the number of personnel interviewed, this value will still be affected by the limits of each individual's vision. The ability of personnel, even in leadership and management positions, to accurately evaluate the importance of facilities outside of their own organizations will result in a significant bias. In addition to increasing the size of the survey pool, the inclusion of additional data groups mitigates the effects of the unavoidable survey error.

The MCE methodology also has several key limitations. By incorporating from the customer assigned criterion weights some subjectivity is introduced into the alternative layout scores (Voodg, 1983). The lack of additional quantitative data types, which drove the modeling of each objective on a single proxy variable, introduces a high dependency between each criterion and its proxy variable. Associated with this relationship, the ability for each proxy variable to accurately and fully represent the objective it is assigned to increases probability of error in each criterion score (Voodg, 1983). Furthermore, as mentioned in literature there are three requirements tied to the use of MCE. First, criterion weight values are gathered on a quantitative measurement scale and assigned numerical values instead of qualitative measurements (Voodg, 1983). Second, the raw data values are gathered on a ratio scale and relevant to each other (Voodg, 1983). Third, data aggregation must take place through addition (Voodg, 1983). There were no other limitations to be incorporated due to the selection of NA and MCE concepts.

Summary

The above has discussed the how NA and MCE methodologies were used to provide solutions to the two stated investigative questions. The NA methodology transforms functional relationship data into a visual display used in the generation of alternative layouts. The MCE methodology generates a score for each alternative layout based on the multiple objectives identified by the customer. Details were given on the data requirements for this effort. Then, discussion was provided on the data acquisition and manipulation required for the NA methodology, followed by data acquisition and manipulation for the MCE methodology. The next section described the process used to perform a sensitivity analysis on the weights used within the MCE methodology. The last section in this chapter outlined the limitations on the use of both models developed in this research, based on the inclusion of NA and MCE concepts. The next chapter will discuss the results these two methodologies produced.

IV. Analysis and Results

Chapter Overview

This chapter discusses the results produced by the network analysis (NA) and multi-criteria evaluation (MCE) described in methodology. It is divided into those results derived from the network analysis (NA) methodology and those generated from the multi-criteria evaluation (MCE) methodology. The chapter begins with discussion of the NA degree centrality and power results. This is followed by a review of the functional network map displaying the interaction buffer and how this map is utilized as a tool to enhance layout selection. The next section discusses the MCE criterion scores as well as each alternative layout's total score. Alternative layout C is identified as the preferred alternative with respect to the MCE methodology. The final portion of this chapter covers the results of the MCE sensitivity analysis of variation in the criterion weights.

Network Analysis

The methodology for the NA utilized 39 facilities chosen by Moody AFB CE within the ADP study area. These facilities are shown in blue in Figure 5 below.

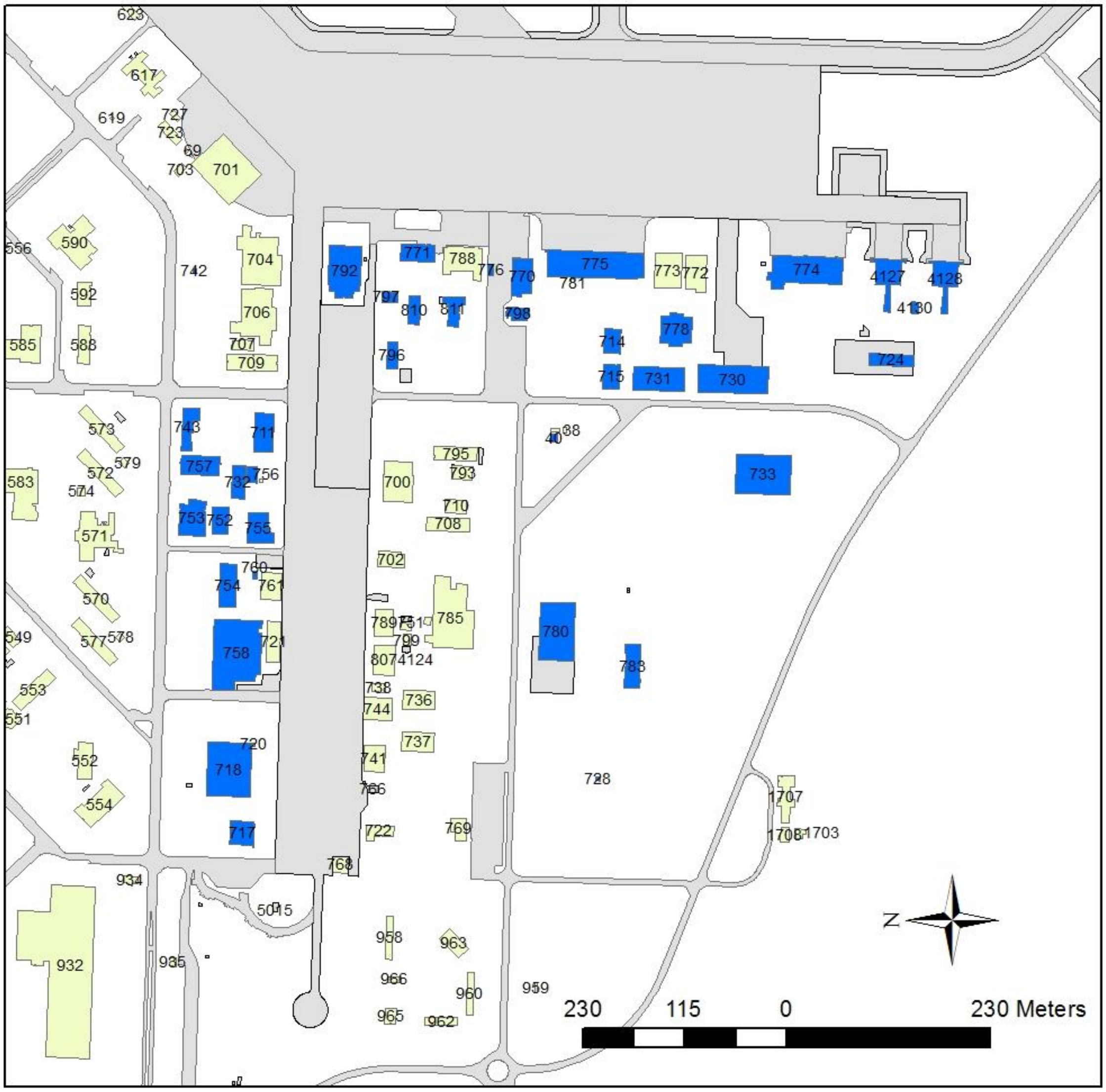


Figure 5. Facilities for NA Methodology

Table 5 below shows the assumed and actual data used to generate the interaction score for each of these facilities.

Table 5. Raw Data for Network Analysis

Facility Number	Given MDI	Assumed Total E-mail Volume	Assumed Number of Facilities Linked	Assumed Local Criticality
40	71	1422	19	172
711	75	19754	28	98
714	67	10713	31	98
715	70	10713	27	172
717	85	14997	15	98
718	70	63606	28	98
724	71	14626	28	39
728	74	495	24	174
730	70	50128	27	39
731	80	32197	32	172
732	75	12185	24	172
733	75	57948	2	98
742	75	441	26	39
743	53	14206	25	98
752	75	11595	26	39
753	67	23938	28	172
754	71	19891	28	172
755	75	18037	5	98
756	75	4760	26	98
757	53	19449	36	98
758	71	82739	33	39
760	59	842	12	98
770	61	19760	37	39
771	85	15914	36	98
774	61	53259	2	98
775	61	66923	14	39
776	70	1574	28	98
778	75	24381	12	98
780	75	54239	37	98
783	88	17594	37	39
792	53	42532	6	172
796	59	7731	30	39
797	71	4381	16	39
798	70	7172	13	98
810	70	8557	35	172
811	70	11225	22	98
4127	95	21586	32	98
4128	95	21586	37	98
4130	75	1986	20	98

Unlike the MCE results discussed below, there are no factor weights applied to the values making up the interaction score. Weights were not applied in this case because these results are used only to demonstrate the feasibility of mapping functional relationship data in order to enhance operations in the ADP study area.

Degree Centrality

As mentioned in methodology, the degree centrality was selected to account for the centrality of a facility within the functional network. For the buildings chosen the assumed results returned from the random number generator ranged from 37 connections (meaning that on a day to day basis these facilities interacted with all but one of the evaluated facilities in the network being studied) down to two connections. The impact of the variation due to this range of connections was mitigated by normalizing each value prior to its inclusion into the final interaction score. While the raw scores for this data group varied by 35, the normalized scores only varied from 0.05 to 1. However, this reflects a variation spanning 95% of the total possible. As mentioned above, if planners desire to emphasize this data group, a weighting factor can be applied to the normalized score prior to its incorporation into the interaction score. Table 6 below shows the raw and normalized degree centrality scores for the buildings evaluated.

Table 6. Degree Centrality Results

Facility Number	Assumed Number of Facilities Linked	Degree Centrality
40	19	0.51
711	28	0.76
714	31	0.84
715	27	0.73
717	15	0.41
718	28	0.76
724	28	0.76
728	24	0.65
730	27	0.73
731	32	0.86
732	24	0.65
733	2	0.05
742	26	0.70
743	25	0.68
752	26	0.70
753	28	0.76
754	28	0.76
755	5	0.14
756	26	0.70
757	36	0.97
758	33	0.89
760	12	0.32
770	37	1.00
771	36	0.97
774	2	0.05
775	14	0.38
776	28	0.76
778	12	0.32
780	37	1.00
783	37	1.00
792	6	0.16
796	30	0.81
797	16	0.43
798	13	0.35
810	35	0.95
811	22	0.59
4127	32	0.86
4128	37	1.00
4130	20	0.54

Power

The power component of the NA measures each facility node's ability to influence the flow of resources through the functional network. Unlike the degree centrality this value is comprised of three data groups. The mission dependency index (MDI) subcomponent of the power score was the only data group not based on assumed values. For the studied facilities this raw score ranged from 53 to 95. This resulted in a normalized variation of 46%. Within the source document for MDI values very few facility types scored below 40 or above 90, as such the raw values used in this effort are a good representation of the variation expected (USAF, 2012). Unlike the MDI raw data, the actual e-mail volume data was not available for this research effort. The simulated volume of e-mails sent and received per week in these facilities varied from approximately 82,738 to 440. These raw scores were highly depended on the variation in facility size, varying from approximately 42,800 square feet to 230 square feet. Similar to other data groups in the NA portion of this effort; the raw data varied by a factor greater than 100. The normalization prevented this data group from completely dominating the final interaction score. However, it should be noted that the resulting variation of 99% is the greatest for any data group used in the NA. The survey scores used to generate the local criticality component for each facility node's power, were also based on assumed values. The total of 39 interviewees combined with 100 criticality points per interviewee, limited the total points available to 3900. Scores were assigned based on the importance groups with values ranging from 39 to 174. Once normalized the variation of this data group differed from 0.22 to 1. Table 7 below shows the raw, normalized and final power score for the buildings evaluated.

Table 7. Power Results

Facility Number	Given MDI	Normalized MDI	Assumed Total E-mail Volume	Normalized E-mail Volume	Assumed Local Criticality	Normalized Local Criticality
40	71.00	0.75	1422.30	0.02	172.00	0.99
711	75.00	0.79	19754.20	0.24	98.00	0.56
714	67.00	0.71	10713.02	0.13	98.00	0.56
715	70.00	0.74	10713.02	0.13	172.00	0.99
717	85.00	0.89	14996.56	0.18	98.00	0.56
718	70.00	0.74	63606.45	0.77	98.00	0.56
724	71.00	0.75	14626.43	0.18	39.00	0.22
728	74.00	0.78	494.89	0.01	174.00	1.00
730	70.00	0.74	50127.85	0.61	39.00	0.22
731	80.00	0.84	32197.27	0.39	172.00	0.99
732	75.00	0.79	12185.22	0.15	172.00	0.99
733	75.00	0.79	57948.43	0.70	98.00	0.56
742	75.00	0.79	440.83	0.01	39.00	0.22
743	53.00	0.56	14206.39	0.17	98.00	0.56
752	75.00	0.79	11594.68	0.14	39.00	0.22
753	67.00	0.71	23937.94	0.29	172.00	0.99
754	71.00	0.75	19891.44	0.24	172.00	0.99
755	75.00	0.79	18036.63	0.22	98.00	0.56
756	75.00	0.79	4759.72	0.06	98.00	0.56
757	53.00	0.56	19448.53	0.24	98.00	0.56
758	71.00	0.75	82738.92	1.00	39.00	0.22
760	59.00	0.62	842.15	0.01	98.00	0.56
770	61.00	0.64	19760.44	0.24	39.00	0.22
771	85.00	0.89	15913.57	0.19	98.00	0.56
774	61.00	0.64	53259.41	0.64	98.00	0.56
775	61.00	0.64	66923.08	0.81	39.00	0.22
776	70.00	0.74	1574.10	0.02	98.00	0.56
778	75.00	0.79	24380.85	0.29	98.00	0.56
780	75.00	0.79	54238.80	0.66	98.00	0.56
783	88.00	0.93	17593.72	0.21	39.00	0.22
792	53.00	0.56	42531.84	0.51	172.00	0.99
796	59.00	0.62	7731.17	0.09	39.00	0.22
797	71.00	0.75	4381.27	0.05	39.00	0.22
798	70.00	0.74	7171.82	0.09	98.00	0.56
810	70.00	0.74	8556.69	0.10	172.00	0.99
811	70.00	0.74	11224.55	0.14	98.00	0.56
4127	95.00	1.00	21586.15	0.26	98.00	0.56
4128	95.00	1.00	21586.15	0.26	98.00	0.56
4130	75.00	0.79	1985.82	0.02	98.00	0.56

Functional Network Map

The interaction scores for each building ranged from 1.46 to 3.08. While this does not appear to indicate a high degree of difference between these facilities, the normalization of the four data groups constrains the possible range between 0 and 4. Accounting for the total possible range of values the simulated results reflect a variation of just more than one half of the total possible. Table 8 below shows the interaction score and the buffer values used.

Table 8. Total NA Values

Facility Number	Total Degree Centrality	Total Power	Interaction Score
40	0.51	1.75	2.27
711	0.76	1.59	2.35
714	0.84	1.40	2.24
715	0.73	1.85	2.58
717	0.41	1.64	2.04
718	0.76	2.07	2.83
724	0.76	1.15	1.91
728	0.65	1.78	2.43
730	0.73	1.57	2.30
731	0.86	2.22	3.08
732	0.65	1.93	2.57
733	0.05	2.05	2.11
742	0.70	1.02	1.72
743	0.68	1.29	1.97
752	0.70	1.15	1.86
753	0.76	1.98	2.74
754	0.76	1.98	2.73
755	0.14	1.57	1.71
756	0.70	1.41	2.11
757	0.97	1.36	2.33
758	0.89	1.97	2.86
760	0.32	1.19	1.52
770	1.00	1.11	2.11
771	0.97	1.65	2.62
774	0.05	1.85	1.90
775	0.38	1.68	2.05
776	0.76	1.32	2.08
778	0.32	1.65	1.97
780	1.00	2.01	3.01
783	1.00	1.36	2.36
792	0.16	2.06	2.22
796	0.81	0.94	1.75
797	0.43	1.02	1.46
798	0.35	1.39	1.74
810	0.95	1.83	2.77
811	0.59	1.44	2.03
4127	0.86	1.82	2.69
4128	1.00	1.82	2.82
4130	0.54	1.38	1.92

The interaction score was then combined with buffer polygons introducing a spatial aspect to these values. The resulting map shown in Figure 6 below, highlights areas in green where the siting of new facilities is desirable with respect to the functional network.

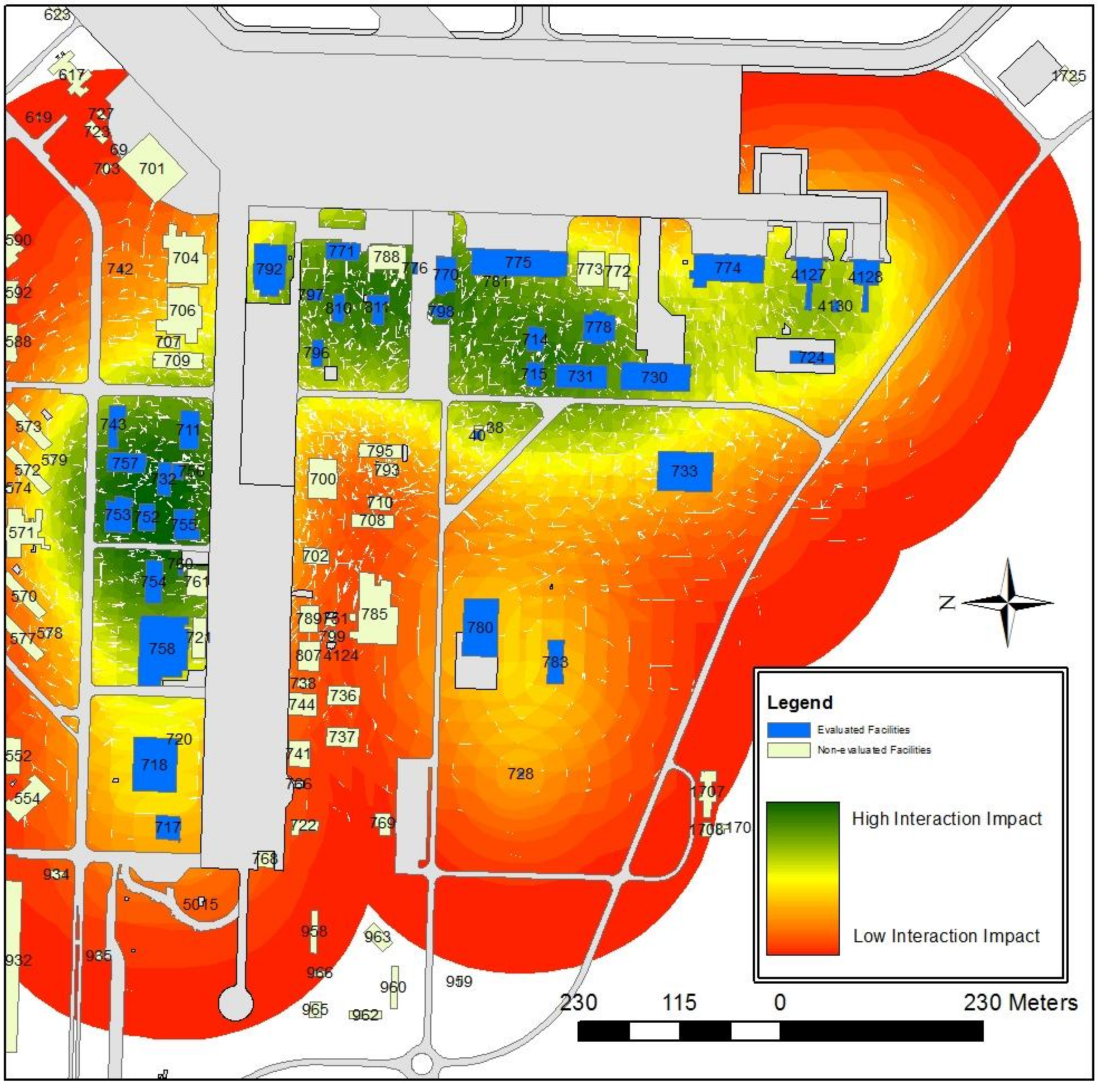


Figure 6. Functional Relationship Map

This map identifies areas adjacent to the groups of facilities with higher interactions scores as more desirable locations. Those areas away from groups of facilities or adjacent to buildings with low interaction scores are identified as less desirable. While this map could be added as an additional layer to the constraints map, discussed in Chapter 2, there are two key differences between the functional data being represented here and the constraints data. First, unlike constrains map layers, the buffer sizes shown above are calculated from non-spatial data. For example there is no direct method of mapping an e-mail volume geographically. Typical constraint buffers are based on requirements that are specified in spatial terms, such as those for anti-terrorism force protection standoff or the surveyed boundary of a flood plain. Caution should be taken when displaying a spatially based buffer on the same map as non-spatially based one. Secondly, a constraints map buffers areas where new facilities should not be sited; this generates a map where the areas not buffered are desirable for development. The map above illustrates the exact opposite. Here the efficiency of operations is increased when new facilities are sited as far within buffered areas, the green portions, as possible.

Multi-Criterion Evaluation

On both the 75% and 90% ADP submissions by Adkins, four alternative layouts were identified. These layouts are the key inputs that were evaluated in the MCE methodology. As described in Chapter 3 above, a total of five objectives were transformed into five criterion and evaluated through the use of five proxy variables. Unlike the NA just discussed all required data was provided for this methodology. The

first proxy variable evaluated was the growth of overall facility square footage detailed in each alternative layout. The raw data varied from 17,348 square feet to 54,851 square feet of additional facility area required. While each alternative evaluated the relocation of the same three agencies, requiring the same amount of new construction, there were variations in the facility demolition requirements. Certain alternative layouts sited new facilities on top of existing facility footprints. The difference in the amount of demolished square footage required produced a variation of 69% in the normalized score. The second proxy variable used in the MCE calculation involved the acres of land remaining available after construction of an alternative layout. This raw data is based on the land parcels identified as available in the Adkins plan and ranged from 4.55 acres to 8.05 acres, resulting in a normalized variation of less than 50%. The third proxy variable was the total distance between each new agencies location and all other facilities in the ADP study area. These values ranged from 74,010 feet to 89,654 feet; however, this resulted in a normalized variation of less than 20%. The fourth proxy variable was also a distance measurement. In this case the average distance was measured from each agency's new location to the flightline. Values ranged from 60.5 meters to 187.5 meters with a normalized variation of approximately 68%. The final proxy variable was the number of new facilities constructed. These raw scores ranged from one to three with a normalized variation of 67%. The tables below show the proxy variables to include the raw and normalized scores.

Table 9. Facility Growth, Available Area and Distance Between Scores

Alternative Layout	Facility growth (Sqft)	Normalized facility growth	Available area remaining (acres)	Normalized available area	Distance between facilities (feet)	Normalized distance between facilities
A	51140.00	0.93	4.55	0.57	74010.00	0.83
B	51140.00	0.93	4.55	0.57	79468.00	0.89
C	17348.00	0.32	8.05	1.00	89654.00	1.00
D	54851.00	1.00	5.09	0.63	82543.00	0.92

Table 10. Distance to Flightline and New Building Scores

Alternative Layout	Distance to flightline (meters)	Normalized distance to flightline	Count of new buildings (each)	Normalized new buildings
A	107.00	0.57	1.00	0.33
B	122.67	0.65	3.00	1.00
C	60.50	0.32	2.00	0.67
D	187.50	1.00	2.00	0.67

Table 11 below shows the weighted score for each proxy variable as well as the resulting total score for each alternative layout.

Table 11. Alternative Layout Scores

Alternative Layout	Weighted facility growth	Weighted available area	Weighted distance between facilities	Weighted distance to flightline	Weighted new buildings	Total Alternative Score
Weight Points (x/100)	25	15	30	25	5	
A	-23.31	8.48	-24.77	-14.27	-1.67	-55.53
B	-23.31	8.48	-26.59	-16.36	-5.00	-62.78
C	-7.91	15.00	-30.00	-8.07	-3.33	-34.31
D	-25.00	9.48	-27.62	-25.00	-3.33	-71.47

As Table 11 shows, the MCE analysis identified Alternative layout C as the most desirable solution based on the objectives evaluated. Layout C generates the least negative value in the total alternative score column. Of the five proxy variables used only one, available area, is aggregated into the total score as a positive value. The other four proxy variables reflect negative values because the proxy variable scores indicate an undesirable outcome with respect to the objective they are associated with. For example to minimize facility growth the proxy variable would measure the change from both square feet constructed and square feet demolished. Thus the higher the proxy variable score the less desirable the alternative would be. Furthermore, it is not surprising that all the total scores are negative values and the preferred option is the least negative score. Since the scores are only significant relative to each other, the return of negative values is not a concern. While Alternative C scores slightly higher, i.e. least desirable, on the most heavily weighted factor, distance between facilities, it scores significantly better on all other factors with the exception of new buildings. The reasons for the difference between Alternative C's scores and the other alternatives becomes apparent when the proposed new facility locations are compared visually, see Appendix A. The site plan for Alternative layout C places the two new facilities on top of the existing buildings 704 and 709 which generates a larger amount of required facility demolition, thus explaining the difference between C's score and the other alternatives in the facility growth factor. Moreover, the location of both new buildings in parcels currently in use returns the highest score for C in the remaining area available factor. The more northern location of Alternative C within the ADP study area explains why it scores lower in the distance between facilities when compared to the more centrally located A, B and D alternatives.

Finally, a visual inspection shows that Alternative C is closer than any other to the flying apron resulting in the best score for distance to flightline. A count of new facilities explains why Alternative A scored better than the other alternatives in the new building factor.

Multi-Criterion Evaluation Sensitivity Analysis

The subjective nature of the assignment of criterion weights is both an advantage when using the MCE approach as well as a cause for concern. It is through the incorporation of criterion weights that priority is assigned to objectives. This is a significant benefit not available in all other multi-criteria decision making models. However, the possible skewing of results based on the influence of subjective criterion weights is a cause for concern, as discussed in Chapter 3. For this research effort the impact of the criterion weights influence was evaluated through a sensitivity analysis. The results of this analysis for each criterion and its associated ADP objective are shown below in Figures 7 to 11.

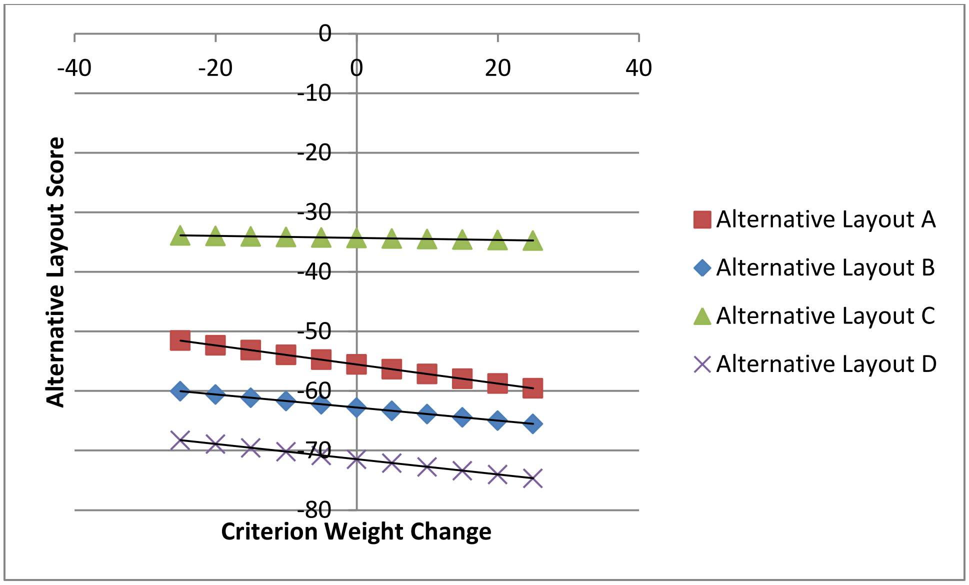


Figure 7. Criterion 1 Facility Consolidation

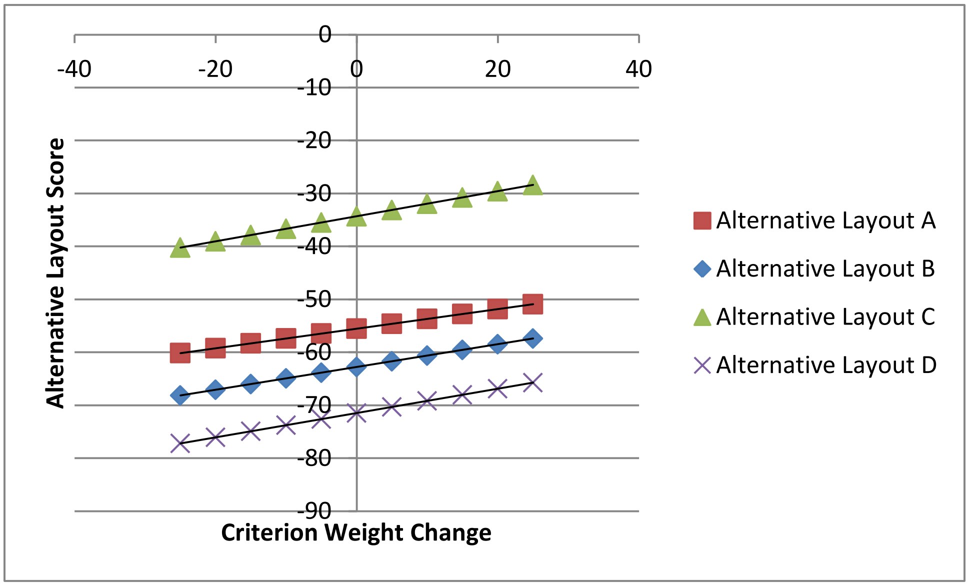


Figure 8. Criterion 2 Flexibility

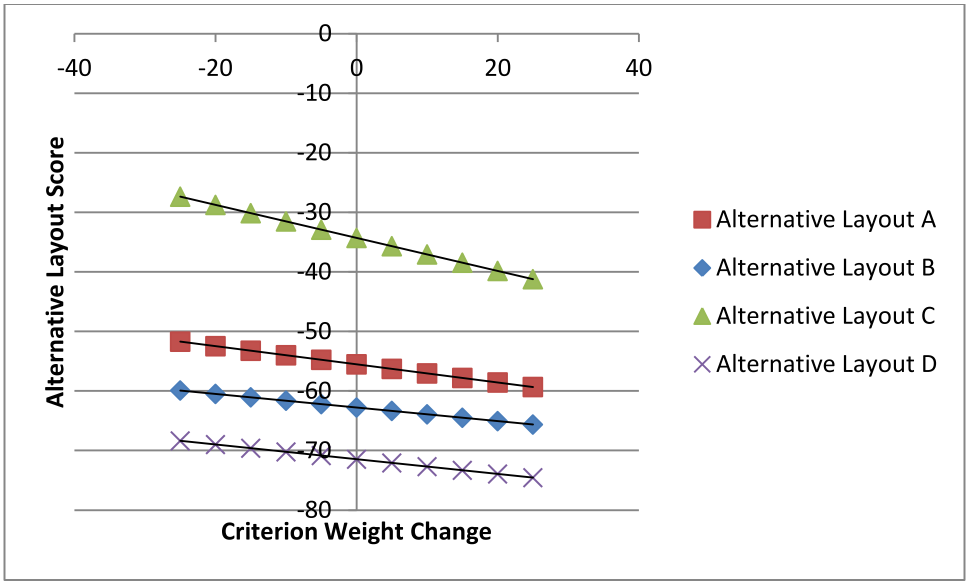


Figure 9. Criterion 3 Circulation

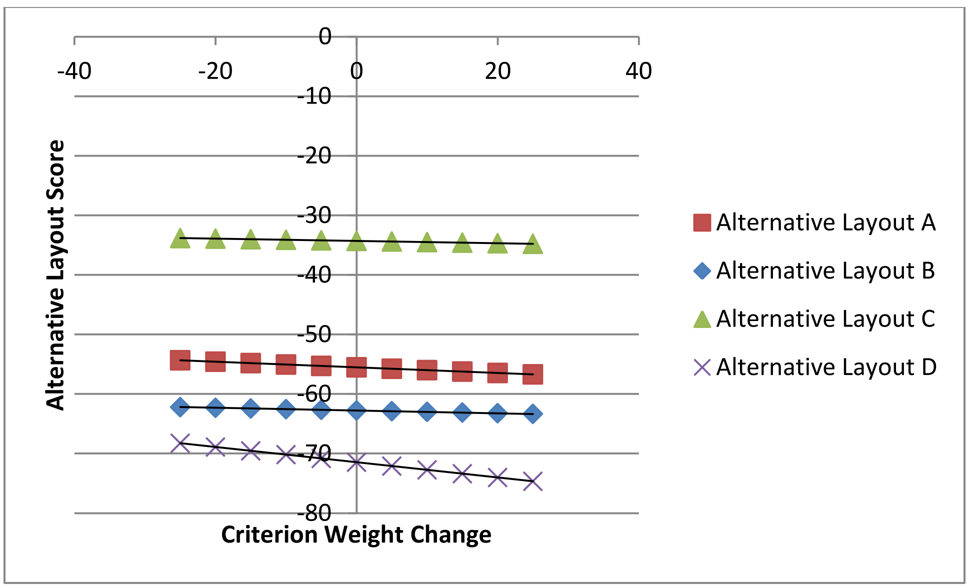


Figure 10. Criterion 4 Flightline Proximity

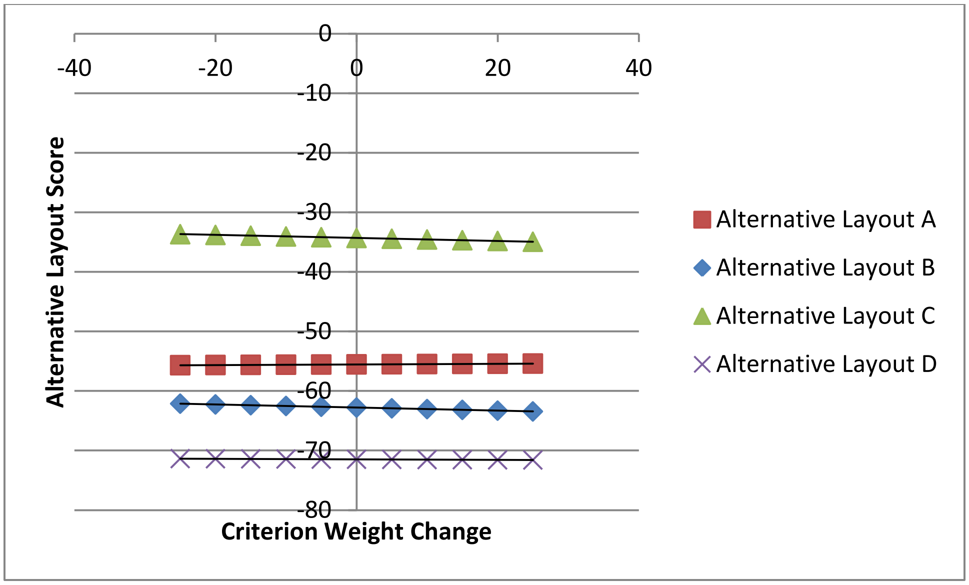


Figure 11. Criterion 5 Personnel Consolidation

As illustrated above, in no case, within the sensitivity range evaluated, does a change in criterion weight result in a change in the preferred alternative layout. In fact there is no case were the variation in criterion weight results in a change in the ranking in any of the four alternative layouts. MCE criterion one and its objective of facility consolidation is the most sensitive to a change in criterion weight that would result in a different ranking of alternative layouts. However, this criterion's significance would have to be reduced well beyond the 25% evaluated to generate a change in the preferred alternative layout. Overall, the largest variance in score within the 25% range occurs in Alternative C for criterion 3, the circulation objective. The criterion that experienced the largest average variation due to a change in criterion weight was criterion 2 with the objective of flexibility. In contrast criterion five is almost insensitive to a change in the criterion weight. In summary, the sensitivity analysis results reveal no change in alternative ranking within the sensitivity range evaluated.

V. Conclusions

Chapter Overview

The first section of this chapter reviews the relationship between the original investigative questions posed and the key results uncovered through this research. The next section discusses the significance of the research completed. This is followed with a discussion of the research applicability. The final section of this chapter describes future research opportunities. Ultimately, the facility layout problem specifically, and urban development in general, remains a vital and dynamic discipline where the emergence of new tools is driving the development principles and processes.

Investigative Questions

This research effort explored possible solutions to two separate investigative questions within the research objective of utilizing network analysis (NA) and multi-criteria evaluation (MCE) methods to develop improvements in the current ADP process. The following reviews these two questions and identifies key results from the completed analysis.

The first question posed by this effort is "How can functional relationship data, readily available to planners, be transformed into a product to improve the ADP layout generation process?" The first key finding was the identification of available data types accessible to planners that could represent functional relationships. The next finding was the identification of two components within NA that are able to utilize functional relationship data. A single data type was identified for degree centrality and simulated survey data was used to meet this requirement. Then, three data types were identified to

constitute the power component, mission dependency index, e-mail volume, and survey data. Following data type determination, the next key development was the conceptual connection between a measurable value generated from degree centrality and power and an enhancement of the functional relationships within the ADP area. This resulted in a conclusion that enhancing function efficiency, measured by a reduction of decision time, can be accomplished by minimizing the distance between facility nodes. Furthermore, by using ArcGIS to combine the interaction score with buffer polygons, the ADP study area can be mapped to optimize the functional network with regard to minimizing facility separation, while accounting for the differing centrality between facility nodes. These key elements resulted in a map that captures functional network data and can be used as a decision support tool for the generation of alternative facility layouts.

The MCE method addressed the second research question. This question was "What approach can be utilized to prioritize alternative facility layouts?" The use of the Near command in ArcGIS was a key element in the completion of this analysis. Combining this command with the ArcGIS facility map eliminated the labor intensive and error prone task of manually measuring distances between facilities. Another key finding was the relative insensitivity of the alternative layout rankings to changes in the criterion weights. Even large changes in criterion weights, +/-25%, resulted in no change to the ranking of the alternative layouts or the MCE preferred Layout C. These elements contributed to the successful development of a second decision support tool resulting in a systematic and explicit process to rank alternative facility layouts.

Significance of Research

The ADP process is a critical component of a systematic approach to managing the development of Air Force installations. Selecting the optimum locations for new facilities represents a decision whose execution requires large amounts of investment capital as well as a decision which has an enduring impact on operations. Beyond the requirement to maintain ADPs for all sub-sections of an installation, changes like those resulting from new mission beddown or BRAC actions can drive an ADP update. The employment of the NA and MCE methodologies described above provides a more analytically rigorous, repeatable, and measurable process. The use of NA to increase the utilization of functional relationship data improves the generation of alternative layout locations by creating a more comprehensive look at operational efficiency. The use of MCE permits both a customization of ADP scoring, to highlight certain objectives, as well as providing additional justification for the selection of a preferred alternative layout over other possible options. Finally, the methodologies above are structured so as to permit base level civil engineer (CE) units to accomplish this analysis in-house. This is advantageous should contract dollars not be available and either a new ADP effort is required or an existing plan requires updating.

Applicability

The scope of the ADP effort evaluated was the relocation of only three agencies. While the application of this effort to deployed locations may appear to be beneficial, attempts to apply these methodologies to locations where the pace and scope of mission change is much greater could render this approach overly burdensome. Therefore these

methodologies should only be applied to stateside installation evaluating similar deliberate changes in facility layouts. The processes described are structured for organizations that possess in-house public works departments with knowledge and resources similar to Air Force CE squadrons. Several details of the application of these methodologies are tailored to fit into the deliberate planning process as described in AFI 32-7062, and specifically to be applied ADPs. As such, a strict application of this approach limits its use to Air Force installations and the ADP process. However, with slight adjustments a general application of the approach discussed above could be utilized by a wider group of organizations against a broader range of facility location issues.

Within the NA methodology development, four data types were identified but only one was available for inclusion. Two simulated data types were based on surveys, the time required for survey approval, generation and data collect was not available for this effort. The other simulated data type, e-mail volume, also required an approval timeframe outside of this research window. Time and resources needed to code and monitor a network counter for the 39 inhabited facilities in the ADP area were prohibitive.

For the NA methodology, regardless of the linking assumptions between function location and increased speed of decision making, the basic relationship between the reduction of separation between functions and increased efficiency is well established. A developed area of research supporting this relationship is research evaluating the facility layout problem. Regardless if it is analysis of functions internal to facilities such as the work by Meller and Gau or functions dispersed in multiple facilities such as the work by

Snyder this relationship generally accepted as valid (Meller & Gau, 1996; Snyder L. V., 2006).

Future Research

There are several opportunities for future research in the facility layout problem that are not explored in this effort. Other aspects of social NA, beyond degree centrality and power, could be investigated to enhance the utilization of relationship data. The application of weighted factors to data groups in the NA method could also be investigated. However, a sensitivity analysis on the resulting interaction scores to fully understand how the chosen weights affect these values should be accomplished. Within the MCE discipline there are analysis types other than weighted summation that could be incorporated to enhance the understanding of tradeoffs between alternatives. One of these approaches, concordance discordance, might be used to quantify the degree of dominance of one alternative over another. Other types of objectives could be incorporated into the MCE methodology. Of specific interest would be objectives that measure both the condition and capacity of utilities available at each prospective layout site. There are also opportunities to calibrate and validate both methodologies described in this research. The incorporation of multiple sets of actual data into the MCE and NA methodologies could investigate the variance and strengths of results. Finally, though the facility layout problem is ill-structured, as discussed in Chapter 1, there are additional opportunities to develop standard methodologies that can be used in support of specific steps within the overall process.

Appendix A: Procedure Log

Data Description

Moody AFB Common Installation Picture - Shapefile

> Available from ACC Data Library (NIPR) access grated by 23d CES/GIO office (Accessed 10 Sept 2012)
> Attributes Used: Airfield Surface, Installation Area, Road Area, Slab Area, Structure Existing Area

SuperRegionPoly V93 – GIS script

> Available from http://arcscripts.esri.com/details.asp?dbid=16700 (Accessed 16 Feb 2013)
> Attributes Used: Python script (.py) and GIS interface code (.tbx)

Interaction Score Spreadsheet

> Available from this research

Evaluated Facilities Spreadsheet

> Available from this research

Generation of Functional Network Map:

1. Open ArcGIS and the shapefile for Moody
2. Right click Structure_Existing_Area, select Data, select Export Data
3. Under Output Feature class select the browse option, change Save As Type to Shapefile and name file Inhabited_Buildings
4. Right click Inhabited_Buildings, select Open Attribute Table
5. Click on Table Options, select Add Field, name field Interaction_score and change Type to Float
6. Open interaction score spreadsheet
7. Manually transpose interaction scores from spreadsheet to Interaction_score column, use Building_No to match
8. Select all records without a matching interaction score and delete them
9. Select Multiple Ring Buffer under Arc Toolbox, Analysis Tools, Proximity
10. Select Inhabited_Buildings as input feature
11. For output feature name new file Multi_Ring
12. Under distances manually input values from 25 to 225 at 25 unit increments (25, 50, 75, …)
13. Under Dissolve Options select None and uncheck Outside Polygons Only
14. Run command by clicking Okay

15. Right click on Multi_Ring and select Attribute Table
16. Click on Table Options, select Add Field, name field Total_score and change Type to Float
17. Right click on Total_score column and select Field Calculator
18. In equation field input “Interaction_score*(250-BUFF_DIST)” and click Okay
Note: BUFF_DIST is an automatic output of the Multiple Ring Buffer Command
19. Download SuperRegion Poly v93
20. Save both .py and .tbx files in same location
21. Right click in Arc Toolbox menu and selected Add Toolbox, select the .tbx file from the saved location
22. Open SuperRegionPoly V93
23. Under Input Polygon Layer select Multi_Ring
24. Under Output Planarized Featureclass input Int_Ring
25. Under Output Lookup Table input Tab_ring
Note: Even though the table is not used a unique name must be assigned to run the script properly
26. Under Statistic Field select Total_score and under Statistic select Sum
27. Set xy Tolerance to 1 meter and set Decimal Tolerance to 0
Note: These settings are applied to reduce the computer processing and memory requirements, they result in the small non-attributed polygons that fleck the functional network map
28. Click Run
Note: Sometime when first running this tool the python script cannot be found by the interface code if this occurs right click on the tool select import script and select the python script
29. Right click on Int_Ring and select Properties then click on Symbology
30. In the Show field selected Quantities and Graduated Colors
31. Under Classification select Classify then click on Sampling
32. Change Max Sample Size to 20000 and click okay
Note: The max sample size change prevents a value input error, if this error still occurs go back and increase this value
33. Under Method select Natural Breaks (Jenks) and set Classes to 32 then click okay
34. Under Fields select Total_score and in the Color Ramp pull down select the green to red gradation
35. Right click in the Range column and use the Reverse Sorting command so that the highest values are assigned to green colors and the lowest values assigned to red colors
36. Right Click in the Symbol column and select Properties for All Symbols
37. Under Outline Color select No Color, click Okay
38. In the Layer Properties menu click Okay
39. Drag the Road_Area, Slab_Area, Airfield_Surface_Area, Structure_Exisitng_Area and Inhabited_Buildings above Int_Ring on the Table of Contents menu

40. Drag Inhabited_Buildings above Structure_Existing_Area
41. Select only Road_Area, Slab_Area, Airfield_Surface_Area, Structure_Existing_Area, Inhabited_Buildings and Dissolve_Ring in Table of Contents

Total Distance and Near Command:

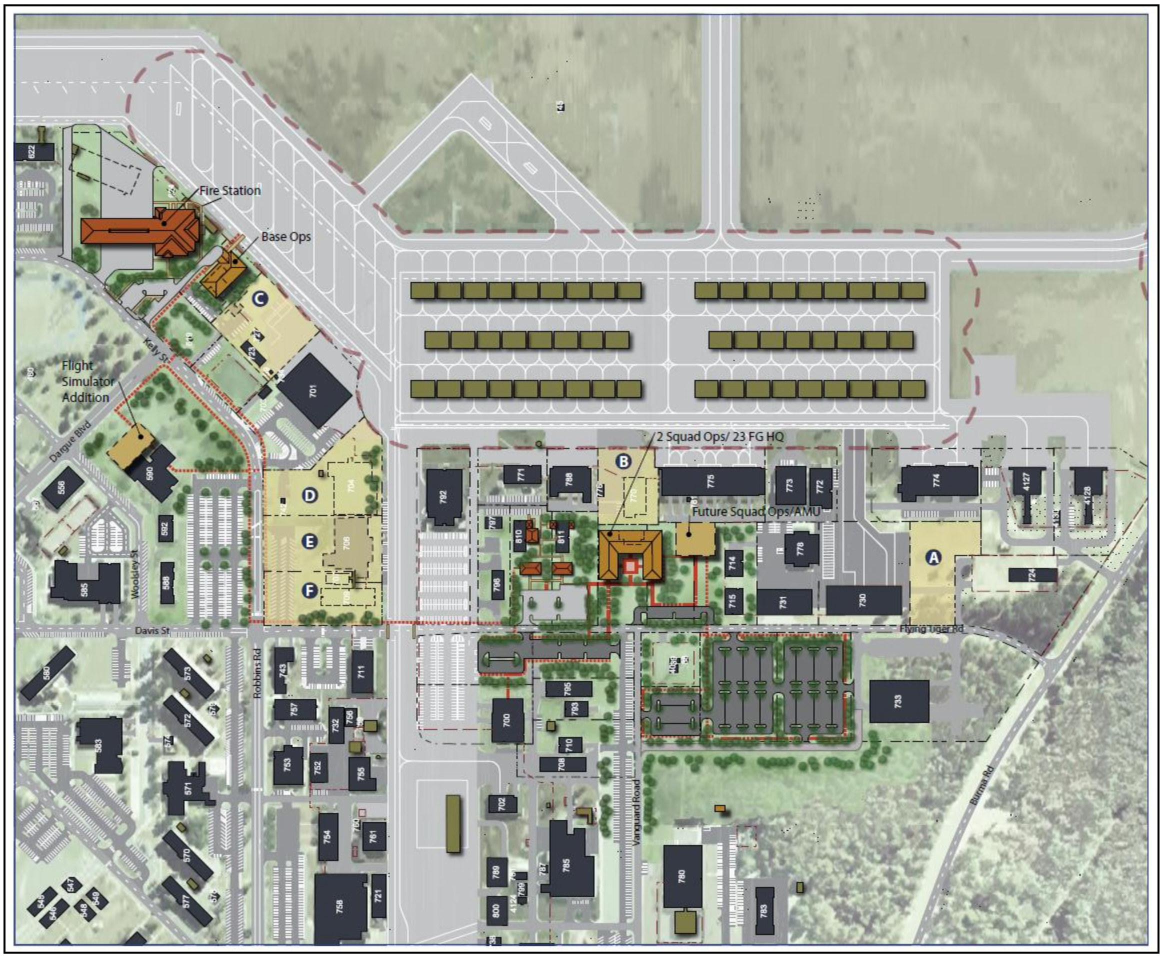
1. Open ArcGIS and the shapefile for Moody
2. Right click Structure_Existing_Area, select Data, select Export Data
3. Under Output Feature class select the browse option, change Save As Type to Shapefile and name file ADPstudyarea
4. Highlight all facilities within the ADP study area
4. Right click ADPstudyarea, select Open Attribute Table, delete all rows not highlighted
5. Right click ADPstudyarea, select Data, select Export Data
6. Under Output Feature class select the browse option, change Save As Type to Shapefile and name file Newbuilding_COAA
7. On the main map screen click Editor then Start Editing
Note: If the Editor toolbar is not showing click the Editor Toolbar shortcut by the map scale at the top of the screen
8. Select Newbuilding_COAA and click okay
9. Right click Newbuilding_COAA, select Open Attribute Table, delete all rows but one then click okay
10. Select the building then click on edit vertices use Modify, Add and Delete vertex to generate a visual match of both the shape and location for the new building as shown in the Adkins plan for COA A
11.Click Editor and select Stop Editing
12. Repeat steps 5 to 11 for each new building specified in all the Adkins COAs, a total of seven times, edit layer names to account for multiple new buildings in certain COAs (ex Newbuilding_COAB1, Newbuilding_COAB2 …)
13. Right click ADPstudyarea, select Data, select Export Data
14. Under Output Feature class select the browse option, change Save As Type to Shapefile and name file COAA
15. Overlay Newbuilding_COAA and identify any facility footprint overlap between the new building and the existing facilities
16. On the main map screen click Editor then Start Editing
17. Select COAA and click okay
18. If a conflict appears modify the attribute table of COAA to remove the conflicting existing building
19. Click Editor and select Stop Editing
20. Repeat steps 13 to 19 to generate a COA layer to correspond to each new building layer, a total of seven times, edit layer names to account for multiple new buildings in certain COAs (ex COAB1, COAB2 …)
21. Select Near under Arc Toolbox, Analysis Tools, Proximity
22. Under Input Features select Newbuilding_COAA

23. Under Near Feature select COAA and click okay
24. Open the Attribute Table of COAA
25. Right click on Near_Dist and select Statistics
26. Record the Sum value
27. Repeat steps 21 to 26 for each set of layers, a total of seven times

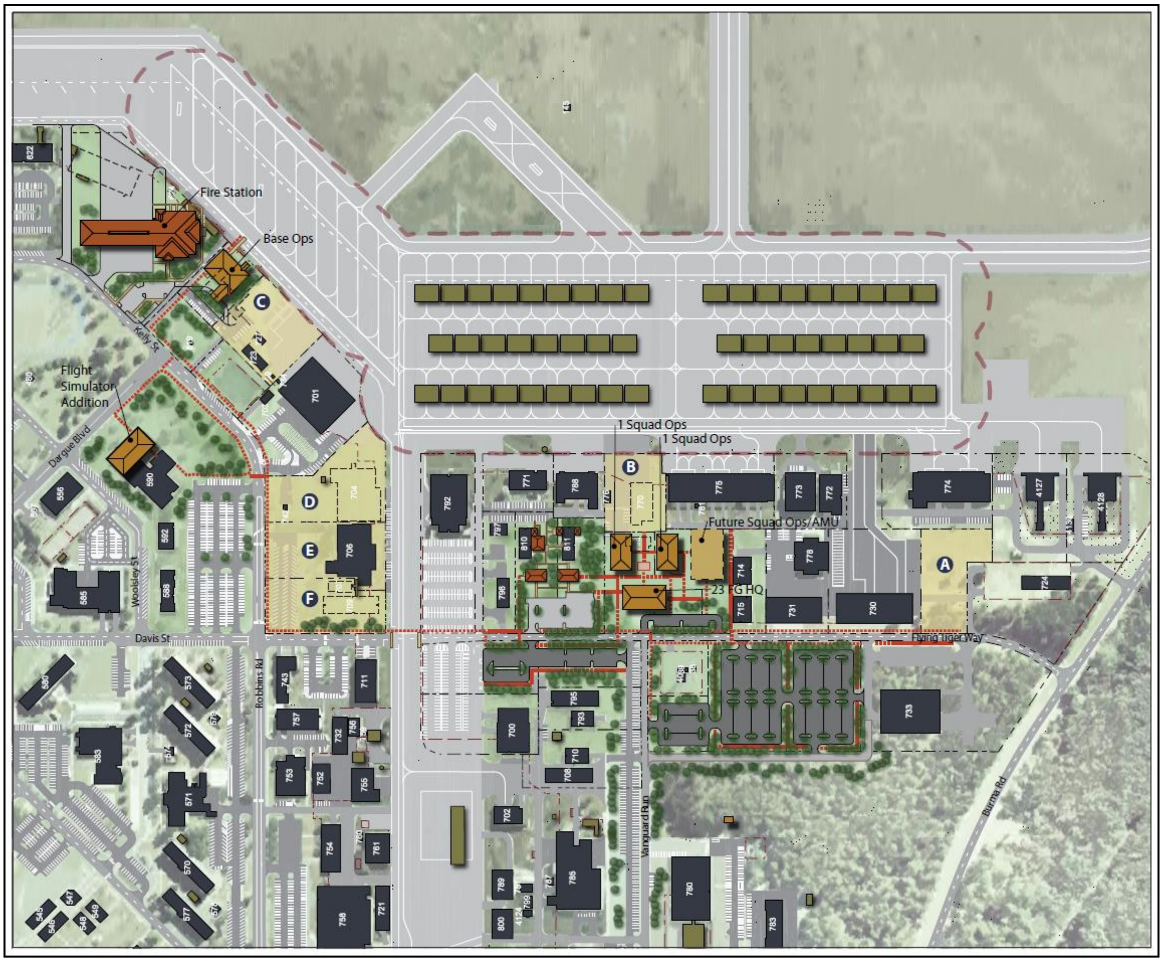
Airfield Distance and Near Command:

1. Open ArcGIS and the shapefile for Moody
2. Right click Airfield_Surface_Area, select Data, select Export Data
3. Under Output Feature class select the browse option, change Save As Type to Shapefile and name file Airfield_near
4. On the main map screen click Editor then Start Editing
5. Select Airfield_Near and click okay
6. Select and delete all non-sole use airfield surface areas (i.e. dog row taxiway)
7. Click Editor and select Stop Editing
8. Select Near under Arc Toolbox, Analysis Tools, Proximity
9. Under Input Features select Airfield_Near
10. Under Near Feature select Newbuilding_COAA and click okay
11. Open the Attribute Table of Newbuilding_COAA and record the value in the Near_Dist column
12. Repeat steps 8 to 11 for each new building layer

Appendix B: Adkins Alternative Facility Layouts

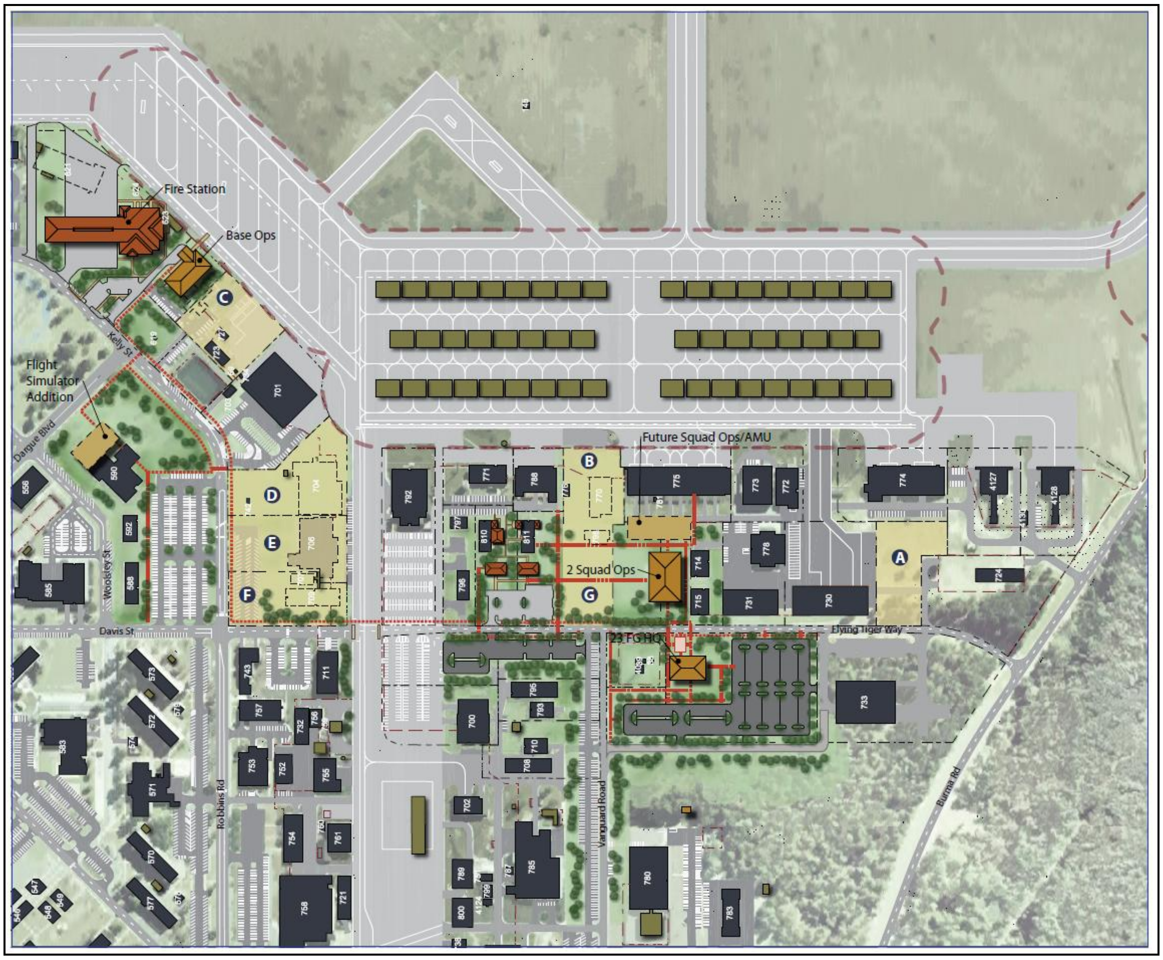


Alternative Facility Layout A (Adkins, 2012)



Alternative Facility Layout B (Adkins, 2012)

Alternative Facility Layout C (Adkins, 2012)



Alternative Facility Layout D (Adkins, 2012)

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14. ABSTRACT The purpose of this research was to develop improvements to the area development planning process. These plans are used to improve operations within an installation sub-section by altering the physical layout of facilities. One methodology was developed based on apply network analysis concepts to the generation of alternative facility layouts. A second methodology was developed using multi-criteria evaluation to the selection of evaluated alternative facility layouts. The results of this study are two methodological processes that can be executed at base level requiring minimal additional information. The functional network map, based in network analysis, increases the use of socio-economic data into the generation of alterative facility layouts. The alternative layout scoring process, base in multi-criteria evaluation, returns a quantitative score for each alternative layout and a relative ranking. The use of these methodologies as decision support tools reduces the subjectivity of the current process and increases the repeatability of results.						
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